PREDICTIVE MODELING OF ALASKAN BROWN BEARS *(URSUS ARCTOS)*: ASSESSING FUTURE CLIMATE IMPACTS WITH OPEN ACCESS ONLINE SOFTWARE

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Abstract

As vital representative indicators of the state of the ecosystem, Alaskan brown bear *(Ursus arctos)* populations have been studied extensively. However, an updated statewide density estimate is still absent, as are models predicting future occurrence and abundance. This kind of information is crucial to ensure population viability by adapting conservation planning to future needs.

In this study, a predictive model for brown bear densities in Alaska was developed based on brown bear estimates derived on the best publicly available data (Miller et al. 1997). Salford's TreeNet data mining software was applied to determine the impact of different environmental variables on bear density and for the first state-wide GIS prediction map for Alaska. The results emphasize the importance of ecoregions, climatic factors in December, human influence and food availability such as salmon.

In order to assess the influence of changing climate conditions on brown bear populations, two different IPCC scenarios (A1B and A2) were applied to establish different predictive climate models. The results of these projections indicate a large expansion of brown bear densities within the next 100 years. High density habitat would thus expand from southern coastal areas towards central Alaska. Based on the modeling results, optimum potential protected areas were determined by means of the program Marxan. According to the outcome, the protection of brown bear populations and bear habitat should accordingly focus on areas along the southern coast of Alaska. The study provides a first digital GIS modeling infrastructure for bear densities in Alaska. Through the pro-active temporal and spatial identification of important brown bear habitats and connectivity zones ahead of time, measures ranging from conservation to the planning of transport facilities could be more effectively focused on minimizing and mitigating impacts to these critical areas before real-world problems occur, as well as in an Adaptive Sustainability Management framework.

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1 Introduction

"*The grizzly bear is invulnerable to all life´s hazards, except the artificial weapons of man*"

(McCracken, 1955)

1.1 Alaska

1.1.1 Topography

Alaska is the northernmost state of the United States and includes four main natural regions: the Arctic Slope, the Rocky Mountain System, the Interior Plateau including the basin of the great Yukon River, and the Pacific Mountain System. The Alaska Peninsula and Aleutian Islands chain, south-central Alaska and the panhandle are the three different sections that can be found along the Pacific coast.

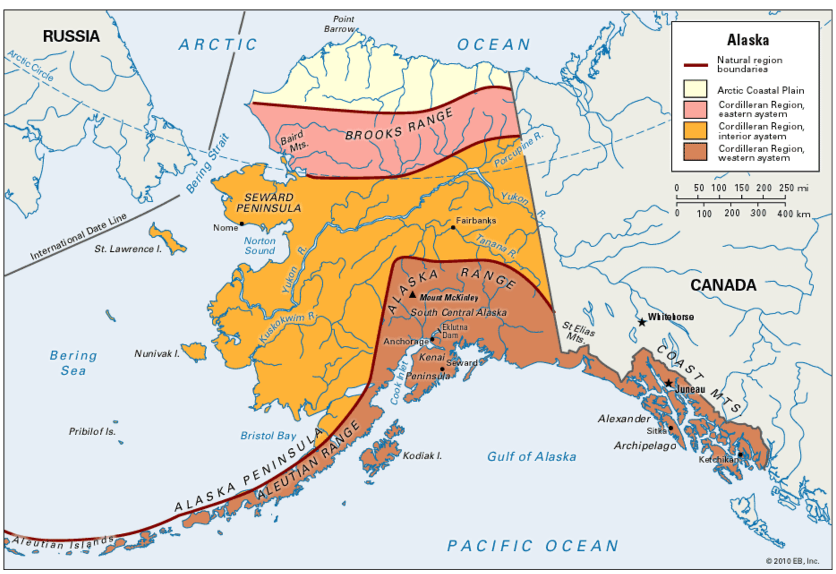

Figure 1: Alaska´s natural regions (Encyclopedia Britannica 2010).

The State covers a total area of 663,267 miles²/1,717,854 km² (U.S. Census Bureau 2000) and has over 70,800 kilometers of coastline (ADNR 2006). North America´s tallest mountain, Mt. McKinley with a height of 6,491 meters is located here, as well as an estimated 100,000 glaciers, more than three million lakes and in excess of 12,000 rivers (ADNR 2010).

1.1.2 Climate

Alaska´s climate varies significantly between the different regions. An annual average precipitation up to 4,000 mm (160 inches) and more occurs in the southeast 'panhandle' and along the northern coast of the Gulf of Alaska. On the Alaska Peninsula, the Aleutian Islands and to the southern side of the Alaska Range, precipitation amounts decrease to nearer 1524 mm. In the interior and further north the precipitation amounts decrease rapidly with an average of 305 mm in the continental zone and less than 150 mm in the arctic region (National Climatic Data Service 2000; Stafford et al. 2000).

In the Southeast, along the South coast and on the Aleutian Islands winters are mild with an average temperature of -7 to 4°C (20- 40°F), whereas the summer temperatures range between 4 to 16 °C (40- 60°F). Interior Alaska is influenced by cold air from Northern Canada and Siberia in winter when temperatures drop to -54°C (-60°F) with an average between -7 to -23°C (20 to -10°F), while summer temperatures vary between 7 and 24°C (45 to 75°F). The Arctic experiences winters with average temperatures of –21 to –29°C (–5 to –20°F) and summers of 2 to 13°C (35 to 55 °F) (National Climatic Data Centre 2000; Stafford et al. 2000).

1.1.3 Vegetation

Covering nearly 2,100 km of latitude and 3,500 km of longitude, Alaska's vegetation varies from the temperate fast-growing rain forests in the south to the low, slow-growing boreal forests of the interior through to the treeless tundra of the north and west and the polar desert in the far north (ADF&G 2006).

Approximately 510,000 km² or around 35 % of Alaska is forested, of which 112,000 km² are classified commercial forests (ADF 2006; Smith et al. 2009). Alaska Native Corporations hold 142,000 km² of non-industrial private forestland (ADF 2010). In coastal Alaska, stands contain mainly western hemlock (*Tsuga heterophylla*) and sitka spruce (*Picea sitchensis*), with occasional stands of red (*Thuja plicata*) and yellow cedar (*Callitropsis nootkatensis*). The interior of Alaska is dominated by stands of black spruce (*Picea mariana*), white spruce (*Picea glauca*), and birch (*Betula kenaica* and *B. neoalaskana*) that are frequently mixed with aspen (*Populus tremuloides*) and black cottonwood (*Populus trichocarpa*). Willow (*Salix bebbiana*) and tamarack (*Larix* *laricina*) occur on boggy flats and muskeg. Tongass forest in the Southeast and Chugach forest in Southcentral Alaska are the largest forests of the United States with 16.8 and 4.8 million acres respectively (USGS 1997).

Forestry is one of the State´s largest industries and provides a sustained production of more than 630,000 m^3 timber annually (Halbrook et al. 2009). Historically, large-scale timber harvest was focused on Southeast Alaska, where the vast majority of logging has occurred in productive forest lands of a lower elevation. Alaskan timber and forestry-related activities and exports were drastically reduced after the 1990s when logging regulations resulted in restricted timber releases and led to the closing of pulp mills in Sitka and Ketchikan (ADF 2006).

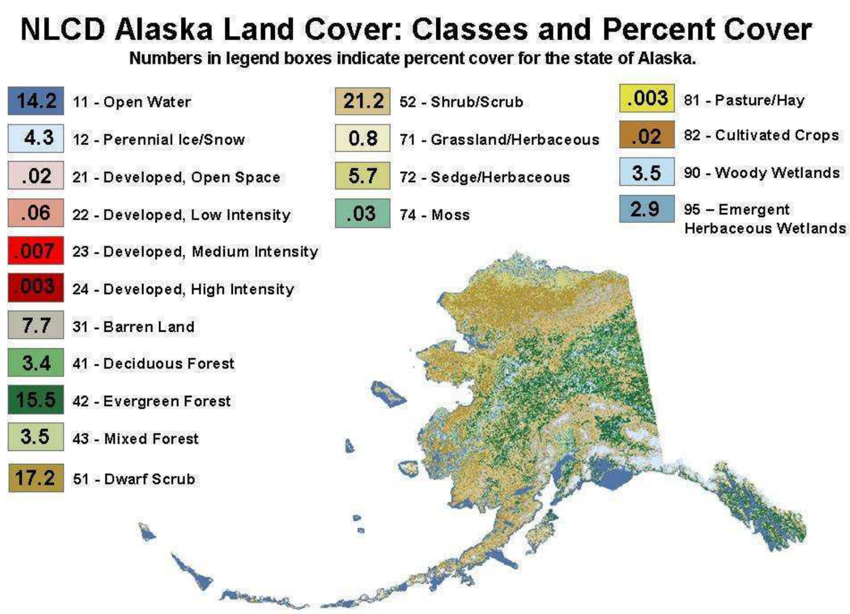

Figure 2: Land cover of Alaska in classes and percent (USGS 2010)

1.1.4 Natural Resources

Alaska´s natural resources, the most significant of which are oil and natural gas, form the base of the country's economy. Alaska produces one quarter of the United States´ petroleum, although oil production has been steadily declining with the approaching depletion of the Prudhoe Bay fields. Modest amounts of petroleum and natural gas have also been produced on the Kenai Peninsula and at the Upper Cook Inlet. The petroleum production reveals various forms of impacts on the Alaskan landscape. The

Alaskan pipeline crosses the country as linear feature from North to South. As a result of the Exxon Valdez oil spill in 1989 2100 km of Alaskan shoreline were fouled and around 250,000 seabirds were killed (WWF 2009). The interests of the petroleum industry and conservation management can still be considered very unalike when it comes to the management and exploitation of important areas for both sides such as the Arctic National Wildlife Refuge.

Furthermore the State yields significant quantities of gold, zinc, silver and lead, as well as modest amounts of metals like antimony, platinum, mercury and tin. After the gold rush in the 20th century, fishing became another important industry, placing Alaska among the world's top seafood producers (Goldsmith 2008). The distributions of harvestable fish stocks, as well as the range of complex socioeconomic factors, define the geographical distribution of marine fisheries (Gates 2010).

1.1.5 Conservation Areas

Around 53% of Alaska has been designated under some form of state or federal protection, ranging from National Parks, Wildlife Refuges and sanctuaries, to recreation areas and state forests (ADF&G 2006).

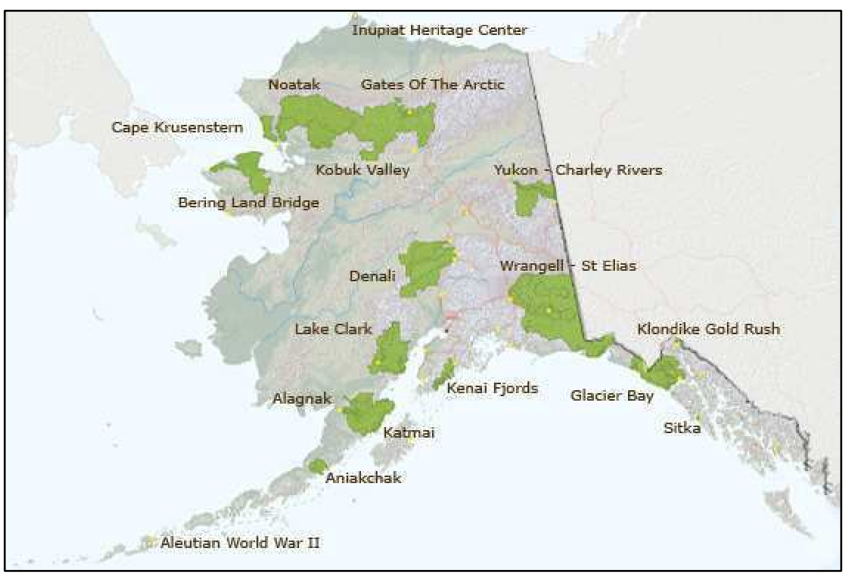

Figure 3: National Parks of Alaska (USNPS 2010)

Figure 4: National Wildlife Refuges (USFWS 2010)

1.1.6 Effects of Climate Change

The warming of the global climate is regarded as the main cause of some of the most accelerated changes in Arctic and subarctic habitats (Durner et al. 2009). According to recent projections, temperatures are predicted to increase from 2.5 to 7.0℃ (A1B scenario), and from 4 to 9℃ (A2 scenario) by the end of the 21st century (Chapman and Walsh 2007).

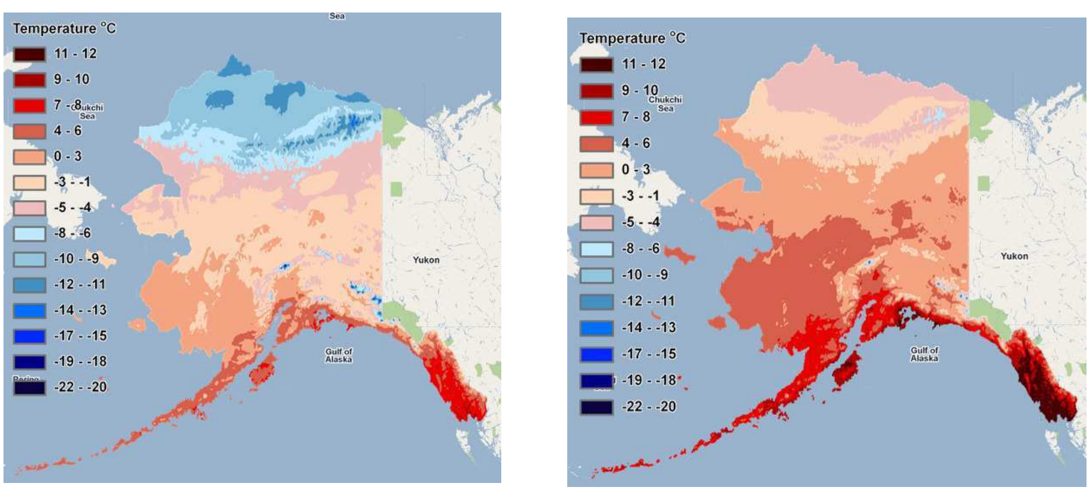

Figure 5: Predicted mean annual temperatures 2000-09 (l.); 2090-99 (r.) (SNAP 2010)

Alaska has already lost 400 billion tons of land ice since 2003 (NASA 2008). In Arctic Alaska, shrub density has been increasing over the last century (Walker et al. 2009; Bhatt et al. 2010), and forest cover across Interior Alaska has been considerably altered by wildfires, disease, and succession (e.g., Hinzman et al. 2005). Based on the climate history and the fossil record of Alaska, it is expected that the predicted warmer and increasingly moist climate will result in continued changes in forest and shrub cover like the expansion of Alaska´s forest into areas currently occupied by tundra (Selkowitz 2009). The anticipated melting of glaciers and subsequent thawing of permafrost layers will consequently lead to rising sea levels, release of stored carbon and damage to lakes, rivers, forests and infrastructure (USGS 1997). Being already affected directly by pollution and physical disturbance, coastal environments are especially vulnerable to climate change due to the dynamic interface between land and sea (Oppenheimer 1989).

1.2 The Brown Bear (*Ursus arctos*)

Figure 6: *Ursus arctos*

1.2.1 Distribution

The historical range of the brown bear (*Ursus arctos*) included large parts of North America, Eurasia and North Africa. In Eurasia they were present from Western Europe as far as the Siberian East coast and the Himalayas, only being absent in Southeast Asia and on the Indian Subcontinent. In Africa their distribution incorporated the Atlas Mountains while in North America they were found up to the Hudson Bay in the North and Northern Mexico in the South (Nowak 1999). North America and Alaska were inhabited by the short faced bear (*Arctodus simus*), the largest carnivorous land mammal of all time, before the originally Euopean *Ursus etruscus* populated the continent during Late Pleistocene. Brown bears are believed to descend from the etruscan bear (Brown 1993). In North America, they have first been described in a scientific context as *Ursus horribilis horribilis* by Lewis and Clarke, who dedicated significant space to them in their expedition journal (Lewis and Clarke 1804; Fritz 2004).

Nowadays the brown bear is still the most widespread bear species with populations in Russia, Japan, North America and parts of Europe. However, the species suffered heavy decline worldwide through hunting and habitat loss. In North America, the reduction of the brown bears´ range started with European settlement. They became extinct in 98% of their historic areas of distribution in the lower 48 States over a 100 year period (Mattson et al. 1995) including, amongst others, California in the 1920s (Storer and Tevis 1955).

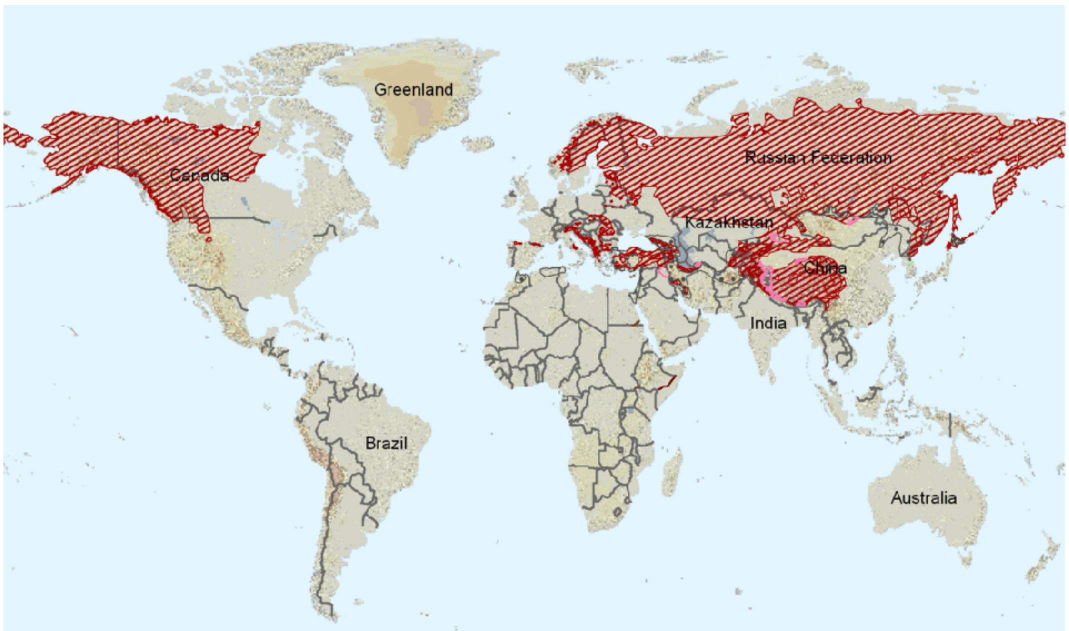

Figure 7: Global brown bear distribution (McLellan et al. 2008)

The largest population of any American state can be found in Alaska where the population is officially believed to be stable and to have remained relatively unchanged since the middle of the 18th century (Miller 1993; Miller and Schoen 1999). In contrast to this, the Kenai Peninsula population was declared a "Species of Special Concern" by the Alaska Department of Fish and Game in 1998 (Schoen and Miller 2002).

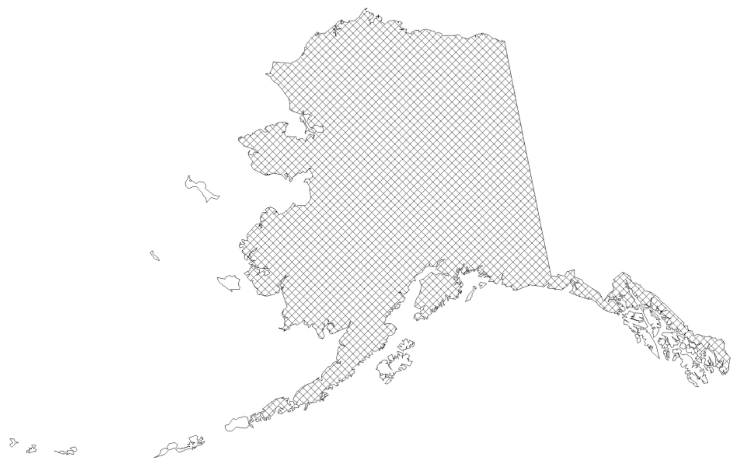

Figure 8: Distribution map of brown bears (*Ursus arctos*) in Alaska (Patterson et al. 2007)

1.2.2 Taxonomy

Brown bears rank among the largest of terrestrial predators. Their size highly depends on sex and age class as well as food abundance (Kaczensky 2000). Male brown bears are generally 1.2 to 2.2 larger than females (LeFranc et al 1987; Stringham 1990; Hilderbrand et al. 1999a). In North America, the heaviest brown bears can be found in the coastal areas of Alaska. There, males have been detected weighing up to 675 kg, with an average of 357 kg for male and 226 kg for female animals, which is mostly related to their diet. A larger body consequently permits the storage of more energy as a buffer to short-term fluctuations in food supply (McLellan 1994). Populations with a better access to large quantities of animal flesh like salmon and ungulates are usually larger than those mainly consuming vegetal diets (Hilderbrand et al. 1999a).

The brown bear has a skeletal structure larger than that of most other bears. It is tetrapedal with plantigrade feet, each foot with five toes ending in a long claw. Important characteristics that distinguish the brown bear from other ursids are its skull, the dental structure, a large hump of muscle overlying the scapulae as well as colour and appearance of the pelage (Craighead and Mitchell 1982). The pelage varies from light blond to black, with some animals showing a silver of cream tipping on the guard hairs (LeFranc et al. 1987). The colour is supposed to be related to habitat use in Alaska (Reynolds 1987), where lighter colours were more common in the interior of the

State and open tundra habitats of the Arctic. Brown bears replace their hair annually and molt is generally completed by late July or August (Nagy et al.1983a).

1.2.3 Reproduction and Life History

Brown bears are characterized by high life expectancy, a rather slow reproduction rate and late sexual maturity. Females reach sexual maturity between four and seven years of age (Craighead and Mitchell 1982). Brown bears are serially monogamous, meaning they mostly have one partner at a time, but this partner varies each season. They live solitary lives except in areas where food supply is very abundant (e.g. salmon streams) and during breeding and cub rearing (Eide and Miller 2008). The breeding season begins at the end of April and generally ends in mid July (occasionally in August) with an average length of 68 days (Craighead et al. 1995; 1998). The 250-300 g hairless cubs are born inside the den in January and February. Litter size ranges from one up to four pups, but twins are most common (Eide and Miller 2008). The cubs leave the den in June and remain under constant and protective supervision of their mothers, usually staying together as a family for 2- 3 years. The interbirth interval depends both on maternal nutrition and litter loss before weaning, and usually averages 3 years (Craighead and Mitchell 1982). Their usual life expectancy lies between 20 and 25 years, however the oldest brown bear found in Alaska was a 39 year old female (Eide and Miller 2008).

1.2.4 Denning Ecology

The denning behaviour is considered to be an elaborate bedding process evolved as a reaction to environmental conditions like weather and the seasonal lack of food (Mystrud 1983), where hibernation of this sort allows bears to avoid the consequences of severe winters (McLellan 1994). Brown bears are referred to as true hibernators implying that they are able to survive up to 7 months without feeding, drinking, defecating, and urinating (Folk et al. 1976; Nelson 1980; Hellgren 1998). However, concerning their body temperature while denning, it is doubted that they fall into “deep” hibernation (Watts et al. 1981, Pasitschniak-Arts 1993). In some southern areas of Alaska like Kodiak Island, brown bears exhibited a “walking hibernation” and were observed travelling occasionally over short distances (Nelson et al. 1983b).

Bears enter the dens earlier in northern areas when weather and the availability of food are unfavourable. Moreover, female bears generally enter dens earlier and leave them later than males, with pregnant females entering the earliest. Duration varies between several weeks for male brown bears up to 7 months for females (Craighead and Craighead 1972; Linnell et al. 2000).

The physiology of the denning habitat depends highly on the availability of suitable spots to the local populations and may be undertaken on forested sites or open tundra (Schoen 1994). Especially in south-eastern Alaska, bears occasionally make use of natural cavities. However, the dens are mostly excavated and roots are considered important for roof stability. In Alaska dens are not reused in the following year since they do not last long enough (Reynolds 1977; Miller 1993).

Another aspect to be considered is the security at the den site, explicitly the level of disturbance around the time of den entry. In this context, the greatest potential impact on bears (e.g. the presence of snow mobiles) is regarded to occur in spring when females and cubs still need to stay close to the den (Mace and Waller 1997).

1.2.5 Feeding and Foraging Habits

Brown bears feed on a variety of plants and animals and are therefore referred to as opportunistic omnivorous generalists. Potential food varies seasonally and regionally and includes insects, vertebrates, fungi and roots as well as angiosperms. During spring and early summer their diet consists mainly of herbaceous vegetation, grasses, forbs and sedges in many ecosystems (LeFranc et al. 1987). Fruits of blueberries, huckleberries (*Vaccinium* spp.), bearberries (*Arctistaphylos* spp.), buffaloberries (*Shepherdia* spp.), devil´s club (*Oplopanax horridus*) and other species are particularly consumed in late summer and fall. In some areas of Alaska, up to 90% of their dietary food energy may be derived from vegetable matter (ADF&G 2010).

Along the Alaskan coastline and streams brown bears feed seasonally on different salmon species *(Onchorhynchus spp.).* Salmon are anadromous, spawning in freshwater and migrating back to the sea as juvenile fish. Salmon can compose up to 95 % of a bear´s diet in coastal habitats during the height of the spawning season and represent the most important source of meat for the largest, most carnivorous bears and for the most productive populations (Hilderbrandt et al. 1999). Six different salmon species can be found in Alaska: the Pink (*O. gorbuscha*), Coho (*O. kisutch*), Chum (*O. keta*), Sockeye (*O. nerka*), Chinook (*O. tshawytscha*), and Steelhead (*O. mykiss)* (State of the Salmon 2002). Fish supply, however, is less abundant in interior Alaska, and brown bears in this area concentrate on roots, corms, bulbs, and ungulates where available (LeFranc et al. 1987). Winter-starved ungulates and neonates including caribou *(Rangifer tarandus)*, moose *(Alces alces)*, elk *(Cervus elaphus)* and bison *(Bison bison)* can be an important part of their diet (Ballard et al. 1981; Larsen et al. 1989; Gunther and Renkin 1990; Hamer and Herrero 1991; Green et al. 1997; Gau 1998). Male brown bears need more protein and are therefore more carnivorous than females (Jacoby et al. 1999). Whenever their habitat overlaps with human settlements, brown bears may also feed on anthropogenic foods like garbage, pet and livestock food, bird seed, human food, honey, and garden crops (Herrero 1985).

1.2.6 Habitat requirements

Being omnivorous generalists, brown bears face relatively broad environmental limits, their habitat includes open landscape and tundra as well as dense forests (Craighead 1998). Habitat use varies seasonally as a result of differences in food availability and quality (Schoen et al. 1994). The timeframe in which to gain enough weight for the next denning cycle is limited to 5-7 months, thus they concentrate seasonally on the most productive habitat which is available (Schwartz et al. 1993).

In Alaska, brown bears inhabit various areas such as old-growth forest, coastal sedge meadows and south facing avalanche slopes. Alpine and subalpine meadows are frequented in early summer. However this does not necessarily represent what were the “best” habitats, since choices are somewhat limited due to human settlement and alteration (Craighead and Mitchell 1982; Gibeau 1998; Schwartz et al. 2003). Brown bears move to coastal habitats between midsummer and fall in order to catch spawning salmon along the streams (LeFranc et al. 1987, Schoen et al. 1994). Habitat quality is believed to be an important indicator of reproductive success as it can contribute directly to the bear´s nutritional condition (Bunnell and Tait 1981; Stringham 1990). Habitat quality for brown bears at both the individual level and the population level is greatly influenced by the availability of meat, particularly salmon (Hilderbrandt et al. 1999). On coastal areas like the Kenai Peninsula, habitat selection in summer is closely related to the presence and abundance of spawning salmon (Suring et al. 1998). However, higher densities than 10 bears/1000km² can be maintained even in generally less populated northern environments in areas where caribou are abundant (Reynolds and Garner 1987).

Furthermore, habitat selection differs between sexes. For example, young females tend to only avoid humans, whereas females with cubs avoid gatherings of others bears, as well as humans and areas accessible for humans. They even choose rivers with less salmon abundance, because bear density is smaller there (Ben-David et al. 2004). However, where human access leads to avoidance of habitats by male brown bears, female bears with cubs may conversely also benefit and prefer these areas (Nevin and Gilbert 2004).

1.2.7 Behavior

Brown bears live in a social hierarchy and are usually shy. The dominant bear controls the occupation of locations and situations like feeding and breeding. This behavior generally enables them to avoid serious fights (Brown 1993). Intraspecific killing occurs among brown bears, with cubs of the year often the most likely victims. However, adult females are also killed, indicating that intraspecific killing is not limited to young bears, but can occur in all age and sex classes (McLellan 1994). Grizzly bears are known to kill one another (McLellan1994), with cubs of the year again the greatest victims, although adult females are also killed. Bears of all age and sex classes are killed which indicates that intraspecific killing is not limited to infants (McLellan 1994).

1.2.8 Home Range and Movement Characteristics

Home ranges are established to enhance efficiency by exploiting familiar rather than unfamiliar areas (McLellan 1985). The varying sizes of brown bears home ranges are reflective of annual food quality, quantity, and distribution (Picton et al. 1985). On the coast where habitats are generally more productive, home ranges tend to be smaller (e.g. on the Copper River Delta 295 km² for males and 174 km² for females), whereas home ranges in the Interior and in the North (e.g. on Noatak River with 1437 km² for males and 993 km² for females) are larger (LeFranc et al. 1987; McLoughlin et al. 1999). In addition, home range size differs between sexes, with males generally having larger home ranges. The higher energy requirement of males as a result of their larger body size is one of the main explanations (McLoughlin et el. 1999) as they would seek to secure an as abundant as possible food supply. Another consideration is the need of males to have access to female bears for breeding reasons and therefore the home range of one male animal might overlap with the home ranges of several females (Bunnell and McCann 1993). On the other hand, females may choose small ranges where food availability is sufficient, but where they can also increase and ensure security of their young. It is for these reasons that females´ ranges can serve as a better estimator for individual minimum feeding habitat requirements (Horn et al. 2008).

Brown bears dispersal capabilities are relatively low compared to other carnivores (Weaver et al. 1996). Movement characteristics are generally influenced by an array of factors such as key food items, breeding, reproductive and individual status, security and human disturbance. Therefore patterns of movement can be observed that vary enormously not only between populations, but also throughout a year, a season, and the life of an individual (Burt 1943; Schwartz et al. 2003).

Brown bears are not territorial and home ranges frequently overlap in areas where food supply is abundant (McLellan and Hovey 2001). Females often demonstrate an intrinsic fidelity to the range of their birthplace whereas juvenile males that have not yet established permanent home ranges can be forced to disperse from their natal range (Nagy et al. 1983a; Nagy et al. 1983b; Blanchard and Knight 1991). In Canada, McLellan and Hovey (2001) detected that male brown bears only dispersed 30 km from their maternal ranges and females only 10 km, while another study by Proctor et al. (2004) revealed 41.9km for males and 14.3 km for females. This may subsequently reduce the recolonization rate of areas where breeding populations have been depleted.

The movement of animals may be limited by discontinuities in an otherwise continuous habitat or in conjunction with the creation of a strip of foreign habitat (Mader 1984; Baur and Baur 1990). This includes natural physical barriers like rivers and slopes, but also encompasses man-made structures like roads. For bears, roads constitute a barrier that is avoided more out of a behavioural necessity (see Chapter “Threats) than as something which they view as an actual physical barrier (Craighead 1998; Nielsen et al. 2002). However, the effect of roads as a barrier to animal movement depends on road width, traffic density, and road clearing width (Baur and Baur 1990; Richardson et al. 1997). Farley (2005) detected a higher probability of road crossings at night time as well as faster and more perpendicular movements when approaching and crossing highways.

1.2.9 Current Status and Management

Although the species is legally referred to as “stable“ and a “species of least concern”, the status of the worldwide brown bear population is not very well known. They have been already eliminated from 50- 70% of their traditional range and the overall number of brown bears worldwide is estimated at approximately 200,000 animals. There are, however, significant differences between the accuracy and reliability of estimates derived from the different continents and countries (McLellan et al. 2008). Many populations are small and remain in isolated areas or small reserves, and are consequently considered threatened (McLellan et al. 2008).

Table 1: Brown bear estimates of the world

Country	**Brown Bear Estimate**
Russia	125,000
Alaska	25,000-39,100 (Miller et al.1997)
Canada	25,000 (Banci 1991)
Southern Europe	185-230
Pakistan	150-200
China	app. 7000
India	500-1000
Japan (Hokkaido)	< 2000 (Mano 2006)

(McLellan et al. 2008)

In Asia, brown bears can be found in Russia, Mongolia, China, India and Japan with the largest number worldwide occurring in Russia. However, in many parts of Asia similar to Southern Europe, conservation status and perspectives are not favourable since populations are mainly small and isolated. In Northern and Eastern Europe there are still some populations in remote and marginal habitat areas, but they are often small, isolated and not really viable (McLellan et al. 2008). Local extinctions are driven by the loss of genetic diversity and an increase of interbreeding due to population bottleneck effects and decreased gene flow (Wright 1977; Wiegand et al. 1998; Waits et al. 2000).

Brown bears are listed in Appendices I and II of the CITES- *Convention on International Trade in Endangered Species of Wild Fauna and Flora*, according to the size of the population: higher populations are listed in Appendix II (trade permitted if it does not harm species' survival), while certain low populations are listed in Appendix I (trade prohibited) (CITES 2010). However, the effectiveness of this measure regarding the prevention of such threats as poaching is questionable.

In the U.S., brown bears are listed as "threatened" in the Lower 48 States under the Endangered Species Act (ESA) of the U.S. Fish and Wildlife Service since 1975, and currently occupy no more than 2% of their historical range (Mattson et al. 1995). Essentially this translates as 98% extinction of genes and habitat. However, the Yellowstone population was (legally) declared recovered and removed from the list in April 2007 (McLellan et al. 2008).

With an estimated 31,700 (24,990-39,136) animals, Alaska contains more than 70 % of the North American brown bear population (Miller et al. 1997). However, these estimates have not officially been updated ever since and are not based on the most recent statistical methods. On the basis of these numbers, the population is considered as healthy and viable by local state departments, although even in Alaska excessive mortality and habitat destruction in areas such as the Kenai Peninsula are leading to decimation (Schwartz et al. 2003; ADF&G 2010a). The Kenai population (with an estimated 277 bears) is already regarded "of special concern" (Del Frate 1993), since it faces the risk of extirpation due to increasing habitat pressure and genetic isolation (Farley 2005).

Table 2: Brown bear density estimates in bear/ 1000 km² for different regions in Alaska

Study Area	Density	Reference
Katmai National Park, AK Peninsula	551 (a)	Miller et al. 1997
Admiralty Island	399-440 (a,b)	Schoen and Beier 1990, Miller et al. 1997
Kodiak Island	323-342 (a,b)	Miller et al. 1997
Chichagof Island	318 (a)	Miller et al. 1997
Black Lake	191 (a)	Miller and Sellers 1992, Miller et al. 1997
Denali National Park	34 (a)	Dean 1987
Western Brooks Range	30 (a)	Miller et al. 1997
Seward Peninsula	18 (a)	Miller et al. 1997
East-central Alaska Range	16	Boertje et al. 1987, Gasaway et al. 1992
Arctic National Wildlife Refuge	16	Reynolds and Garner 1987
South Central Alaska	11-41 (a,b)	Miller et al. 1987, 1997; Miller 1995a;Testa et al. 1998
South-central Alaska Range	10-15 (a)	Miller et al. 1997
Eastern Brooks Range	7	Reynolds and Garner 1987
Arctic National Wildlife Refuge coastal plain	4	Reynolds 1976
Kenai Peninsula	277	Del Frate 1993

(Schwartze et al. (2003): a) Techniques used included estimate of precision; other approaches had no estimates of precision and due to a variety of methods used in their derivation, comparisons must be done cautiously; (b) range reflects different study areas or different times in the same study area).

In Alaska, the brown bear is classified as a game animal with regionally established regulations and legal hunting seasons (Alaska Administrative Code 5AAC 92.990). In some areas, bear hunting seasons are scheduled for spring and fall, whereas in other areas they are only permitted in fall. One hunter is permitted to harvest one bear every four years, except in seven units where it is legal to kill a brown bear every year (Units 6 (except 6D), 12, 19D, 20E, 25D, and portions of 13 and 20D).

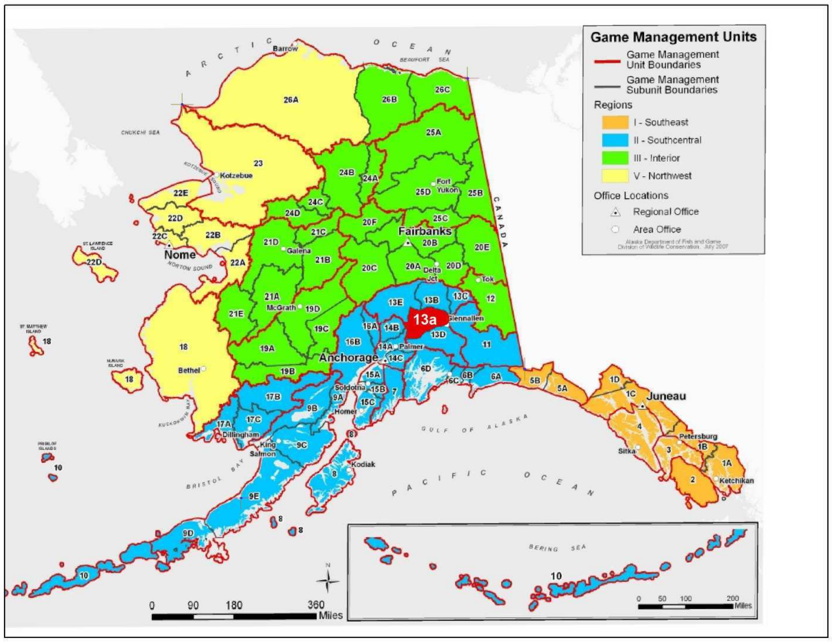

Figure 9: Game Management Units of Alaska (ADF&G 2007) with the highlighted GMU 13A surveyed by Testa et al. 1998.

Harvest is conducted by game wardens and other government hunters for management purposes like population control and reduction of nuisance bears, as well as by sport and trophy hunters (Brown 1993). Brown bears can be legally killed by resident, non-resident, and subsistence hunters who hold both an appropriate license and in most areas a valid tag (Miller and Schoen 1999). However, only 4% of Alaskans are subsistence hunters. Current resources and information based on the number of bears by type of hunting (sports, subsistence, etc.) can be acquired on [http://www.adfg.alaska.gov/index.cfm?adfg=brownbearhunting.harvest] and [http://www.adfg.alaska.gov/sb/CSIS/index.cfm?ADFG=harvInfo.resourceCatData].

Nonresident brown bear hunters are required to have a guide or be accompanied by an Alaskan resident who is a relative. It is illegal to kill newborn and yearling cubs or females with offspring. Brown bears may furthermore be killed in defense of life and property, which entails the obligatory filing of a report (Miller and Schoen 1999; ADF&G 2010b). Hunting and trapping are allowed in national preserves according to Federal and non-conflicting State law and regulations. For a National Park such as the Denali National Park, that means that subsistence hunting by eligible residents is permitted on

ANILCA certified park and preserve lands except former Mt.McKinley NP, and that sport hunting is still permitted within the Denali National Preserve (NPS 2011).

The intensive game management program involved cost in the region of US$ 4,000,000 in 2010 alone. On the other hand, revenues for big game tags declined 39%, non-resident hunting licence revenues 29% and resident hunting licence sales 8% over the last ten years (ADF&G 2010b). According to the report of the Department of the Interior (DOI 2006), the total revenue from hunting was US$ 121,000,000, whereas the revenue from wildlife viewing was US$ 581,000,000, with increasing interest from the public.

Hunting and killing of Alaskan brown bears has increased over the last years (Miller and Schoen 1999). Between 2002 and 2007, official figures show that an average of 1526 brown bears were killed annually, with a total number of 1230 reported kills in 2006/2007 (ADF&G 2007) and around 1900 kills in 2009 (ADF&G 2011). The number of unreported illegal kills is apparently unknown, but suspected to be significant (Miller and Schoen 1999) and may even exceed the number of reported killed bears. The official numbers also fail to include bears that were maimed and injured.

1.2.10 Threats

Brown bears generally occur in low densities due to their large area requirements and low fecundity, making them vulnerable to population decline which is compounded by their slow recovery (Russell et al. 1998; Purvis et al. 2000). Remaining populations are commonly related to areas of low human density revealing the importance of current land-use changes and negative consequences of human-caused mortality (McLellan 1998; Woodroffe 2000; Mattson and Merrill 2002).

Although Alaska is believed to be an area of relatively low human influence, and the Alaskan brown bears to be a stable population, the animals have to face many of the same intolerant attitudes and threats that have led to the reduction or even extirpation of their species throughout its historic range in the lower 48 states and around the world (Miller and Schoen 1999).

Increasing human populations lead to habitat loss, fragmentation and alienation in many areas (McLellan 2008). Industrial development, agriculture, human settlement, plantation forestry, contamination, recreation and other human related activities are the greatest threats to brown bears (McLellan 1990; Gyug et al. 2004; Proctor et al. 2005; Horn et al. 2008). As a result, population units get isolated involving serious and damaging demographic and genetic impacts (Proctor et al. 2004), factors which the IUCN precautionary principles highlight as overwhelmingly negative (Cooney 2004).

- *Roads and Railways*

The density of animal populations and the species richness of communities are often altered and primarily reduced in roadside habitats through habitat alteration (Reijnen et al. 1997; Baker et al. 1998). Appearing as long linear features in the landscape, roads and railways usually have a strong influence on brown bear populations. A direct impact is exerted through habitat alteration and car road mortality (Jackson 2000). Furthermore, the improved access also involves an increased direct mortality due to hunters und poachers (McLellan 1990), as well as an effect on habitat use and human-caused mortality because of increasing the accessibility of the area for recreational human activities (White et al. 1998b). Bears may be displaced from certain habitats, with some populations becoming fragmented. Fragmentation, restriction of movement and disrupted gene flow undermine ecological processes amongst these populations (Jackson 2000). It has been demonstrated that roads can continue to have an effect on wildlife populations for over 10 years even after the actual road construction has been completed (Findlay and Bourdages 2000; Jaeger and Fahrig 2001). Roads related to forestry and logging are often non-permanent and might not be used frequently or over a long period, whereas increased hydroelectric production and mining entails the construction of long-term roads (Horn 2008).

Social structures can be disrupted as in some areas such as a part of Banff National Park, Canada, where adult female grizzly bears are much less likely to cross highways than males (Brown 1993; Gibeau and Heuer 1996; Gibeau and Herrero 1998). In the same study area it has been revealed that all of the recorded 95 human-caused mortalities between 1971 and 1998 occurred up to 500 meters from a road or 200 meters from a trail. Problem wildlife control represented 71 % of these deaths while highway and railway mortality accounted for 19 % (Benn and Herrero 2002). In Western Canada, National Parks were shown to be real population sinks, putting bears at risk of national extinction.

- *Forestry*

The future of brown bears in many parts of the world is inseparably related to forest management (Schoen 1991). The Forest´s value as security habitat, bedding and foraging sites is often altered by current management strategies (Zager et al. 1983; Gyug et al. 2004). Extensive site preparation with heavy machinery causes soil disturbance and, despite the availability of less damaging logging techniques that have been developed over the last decades, clear cutting remains the most common silvicultural approach. Together with plantations it implies the elimination of food resources, for example through decreased berry productivity, although this is juxtaposed by the fact that more berries are found on road areas (Bennett 1991; Forman and Alexander 1998). Furthermore the importance of high value open sites as foraging and security habitats for breeding and roosting sites declines with the intensity of loggings in the adjacent forest site (Gyug et al. 2004; ADF&G 2006). Wildfires are considered beneficial for brown bears, they create open landscapes and can support berry productivity. In this context, the suppression of wildfires is believed to be a population sink. Currently research is being conducted on effects of the 2004 wildfire on brown and black bear populations in Interior Alaska by the ADF&G (Gardner 2009).

- *Hydroelectrics*

The developments in the hydroelectric sector may subsequently increase human access to coastal environments and result in the construction of permanent service roads. Dams are mostly related to mining, emphasizing the interaction of all threats mentioned in this chapter.

- *Recreation*

Recreational activities often influence bears and their habitat directly and indirectly. An example of a negative direct impact in human-bear encounters would be where the encounter leads to self-defensive actions by the person and, ultimately, the death of the bear. Recreation is for the most part also directly related to increased access and better developed infrastructure and consequently addresses some of the same problems as related to roads and direct removal. Recreational activities such as by ATVs and snow mobiles result most often in the disturbance of bears.

Bear viewing is an economically important, but likely less sustainable, recreational activity and can result in the avoidance of viewing areas by some bears, e.g. male adults in Knight Inlet (Nevin and Gilbert 2004). Some bears are able to adjust to impacts of human activities and display habituation patterns which allows them to fish near people in popular bear-viewing areas such as the well-managed McNeil River for instance (Olsen 1996), in other popular areas like Kenai the situation can be of disadvantage for bears. The management of these areas is a crucial factor. However, bears may even prefer these “disturbed” terrains, like females with cubs who chose the safety provided by humans against male adult bears over vegetative cover (Nevin and Gilbert 2004). Avoiding spatial displacement and providing predictable time periods without human activity for food access can minimize the nutritional impacts of bear-viewing programs on brown bears (Rode et al. 2006). However habituation and improper waste management and food storage practices increase the probability of food-conditioning (Mattson 1990), which subsequently may encourage the bears to search for food from people, damaging property and eventually being killed (Herrero 1985). Displacement and habituation interactions have to be considered when addressing the impacts of an increasing human presence (Olsen 1996).

- *Direct removal*

The combination of sport-kills, poaching, inadequately documented kills in defense of life or property (DLP) and subsistence kills can significantly reduce populations (Miller and Schoen 1999). Non-sport kills were predicted to rise relative to the sport harvest with increasing human use in remote Alaska (Miller and Chihuly 1987). On the Kenai Peninsula it has been demonstrated that a higher density of trails, roads, recreation sites and salmon streams resulted in an increased probability of DLP kills (Suring and DelFrate 2002).

- *Contaminants*

Coastal brown bears which mainly feed on salmon are exposed to persistent organic pollutants like DDT, PCBs, and organo-chlorine pesticides that especially accumulate during hibernation and which have potentially fatal consequences (Christensen et al. 2005)

1.3 Objectives

Brown Bears in Conservation Practice

Addressing vertebrate species requirements is a common procedure in conservation planning and is considered easier than trying to protect ecosystems and ecosystem processes (Noss et al. 1996; Noss et al. 1997). It is a first step towards conservation and the brown bear is a suitable and charismatic focal species for various reasons:

- Brown bears are a keystone species (Helfield and Naiman 2006), as they influence prey population, composition and behavior. Moreover, they support the transport of nutrients from aquatic to terrestrial habitats through salmon carcasses, as well as seed dispersal via digestion, and thus contribute to important ecosystem functions (Horn et al. 2009).

- Brown bears function as umbrella species (Maehr 1998; Simberloff 1998). They have large area requirements, a wide range of habitats and their home ranges cover a high range of ecologically diverse communities. Therefore, protecting the brown bear is advantageous for a myriad of other plant and animal species sharing the same habitat (Horn et al. 2009). In some areas this can be relevant when selecting potential reserve locations (Roberge et al. 2004).

- The status of a brown bear population is an applicable indicator for evaluating the state of an ecosystem at lower levels of organization (Schoen et al. 1994). Brown bears have low population densities (except in some concentration areas in high season) and are susceptible to a wide variety of human influences. The productivity of a population can be strongly affected if an ecosystem's functionality is pushed to its limits, for example through significant loss of salmon. Brown bear distribution and abundance is thus able to represent effects of climate change, changes in forage supply and forest biodiversity at a landscape level (Horn et al. 2009).

Brown bear populations have already been eliminated from 53 % of their traditional North American range (Laliberte and Ripple 2004), and brown bears in Alaska face the same intolerant attitudes that have led to their extirpation in other states (Miller and Schoen 1999). Human development will have further impacts on brown bear habitat and climate change is altering environmental conditions, implying positive and rather negative effects on bears. In light of this combination of threats, conserving a species before it irrevocably declines and preventing such a decline will signify a successful biodiversity conservation strategy (Channell and Lomolino 2000a, b). Estimating bear abundance is considered a useful tool as range contractions often occur in areas of high species abundance (Rodriguez 2002). A small decrease in geographical area may subsequently result in a considerable loss of animals (Laliberte and Ripple 2004).

High quality abundance estimates permit documentation of trends in population numbers with certainty and provide critical information needed to understand population dynamics (Miller et al. 1997). Density is usually the most biologically meaningful measure of abundance (Caughley 1977). However, acquiring bear density data is an elaborative and expensive process, especially since, in addition to the actual population estimates, the area also needs to be determined. In Alaska, the traditional capture-mark-recapture technique (CMR) is being substituted more and more by aerial line transects which consequently cover larger areas (see Miller 1987; Becker 2003).

In this context, predictive modeling is an effective, cost-sensitive method to a) estimate current densities and hotspots for the whole state of Alaska, and b) predict environmental changes and thus changes for the species´ density over the coming 90 years. Horn et al. (2008) emphasize the effects of climate change on bear populations as one of the major research questions for the future. This study aims to elaborate a first predictive model for bear densities of the Alaskan mainland under changing climate circumstances. Density maps will be developed in order to detect density hotspots. Furthermore a first evaluation of the effectiveness of protected areas` will also be derived.

the study will offer a first modeling infrastructure, the results of which will serve as a basis for model modifications with updated bear density data as soon as it becomes available. The predictions can be considered for (spatial) population viability analysis and will be helpful for comprehensive decision-making related to brown bear management in a changing climate.

2 Material and Methods

2.1 Brown Bear Data

The initial step was to compile published survey data on absolute brown bear abundance (density bears/ km^2) for Alaska. As this set is incomplete I was not able to obtain all existing data sources. The most comprehensive and up-to-date publications commonly referred to (e.g. IUCN red list by McLellan et al. 2008) are based on the report "BROWN AND BLACK BEAR DENSITY ESTIMATION IN ALASKA USING RADIOTELEMETRY AND REPLICATED MARK-RESIGHT TECHNIQUES" by Miller et al. (1997).

In this study, population estimates for 17 different areas in Alaska were obtained using capture-mark-release techniques and a maximum-likelihood estimator. The study areas () were detected and established with regards to the representative proportion of different habitats used by bears throughout a year. Bears were radio-collared one year prior to the study and the surveys were subsequently conducted during breeding season (May- June) owing to better visibility. Density estimates were derived from data gathered during a series of independent aerial visual searches (replications) to determine the number of marked animals in the population of bears observed on the search area. In order to obtain estimates for the classification category of ´bears of all ages`, offspring accompanying females were counted as marked or unmarked depending on whether the mother was marked or unmarked.The derived population estimates were then used as the base to calculate density estimates which were repeatable, comparable among areas and more objective than former methods which were often lacking measures of precision (Miller et al. 1997). However, in Miller´s study, each member of any group (females with offspring, breeding pairs, and threesomes) was given separate and equal sighting status, so that for example a sighting of a family group consisting of a female with three 3-year-olds was counted as 4 separate observations. This would then consequently bias calculation of CI's, as well as affect the ratios on which the estimate depended.

In this study, areas that were not equally comparable, such as the PCK area which was surveyed in high season only, were excluded from further calculations, thus it was possible to obtain a density estimate for the similar time. The same applies to Kodiak, Admiralty and Chirchanof Islands. Since the objective was to model the terrestrial bear population of Alaska aiming to provide predictions for the conservation and connection of habitats, islands, though part of the brown bear range, have been excluded from further modelling activities.

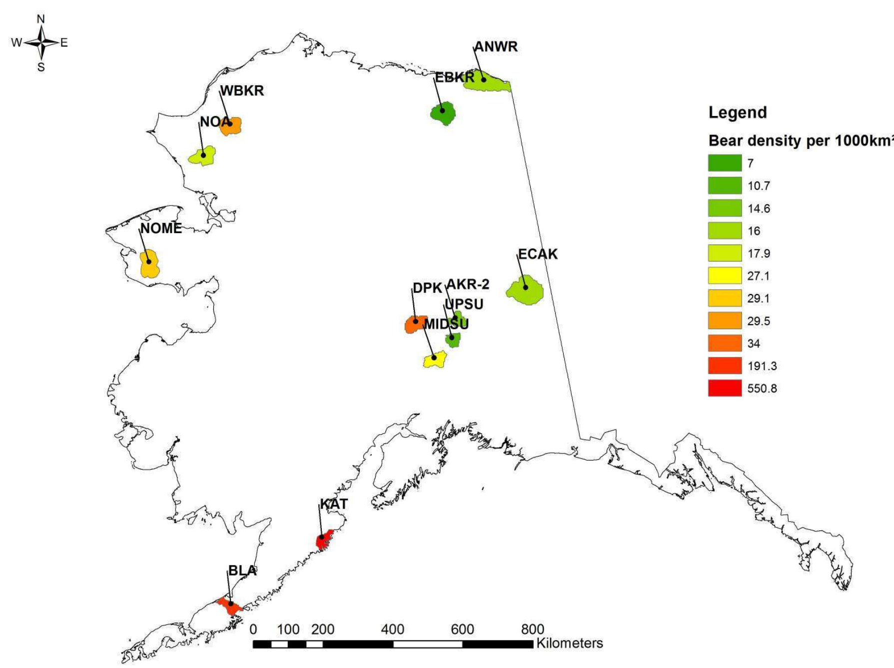

Figure 10: Study areas and brown bear densities used in this study. Selected from study areas in Alaska where brown bear data was obtained from 1985-1992 (Miller et al. 1997).

2.2 Environmental data

Habitat and climate data had to be obtained in order to relate brown bear density to the environment. These environmental variables can have direct or indirect impacts on a species, ranging from proximal to distal predictors (Austin 2002). According to Guisan and Thuiller (2005) selected predictors should best represent the three main types of influences on species:

- Limiting factors like temperature and water that control a species´ ecophysiology

- Resources including all compounds assimilated by an organism (e.g. food)
- Disturbances as any natural or human-caused interferences that affect environmental systems

Based on existing knowledge of brown bear requirements, but also in regard to data availability for the entire study area, 36 independent variables were used for the GIS analysis.

Table 3: Environmental variables

Input Variable	Variable dimension	Format/ Resolution
Elevation	Meters	Raster format
Aspect	Degree (360°)	Raster format
Slope	Degree 0-90	Raster format
Ecoregions 1 and 2	Categorial (0-3/0-8)	Raster format
Mean NDVI from 2000	no dimension	Raster format
Vegetation classes	Categorial (1-23)	Raster format
Temperature in June in December	°C	Raster format
Precipitation in June in December	mm/ day	Raster format
Distance to coast	Meters (1000 m steps)	Raster format- Topographic map to distance
Distance to lakes	Meters (1000 m steps)	Raster format -Topographic map to distance
Distance to rivers	Meters (1000 m steps)	Raster format- Topographic map to distance
Fires 1950-1959 Fires 1960-1969 Fires 1970-1979 Fires 1980-1989 Fires 1990-1999	Categorical presence/absence (1/0)	Raster format
Distrubution salmon Coho Chinook Pink Steelhead Sockeye Chum	Categorical Presence/ absence (1/0)	Raster format
Abundance salmon Coho Chinook Pink	Fish/ salmon biogeo. zone Categorical -9999= N.A. or not present 1= less than 1,000 fish	Raster format

Steelhead Sockeye	2= less than 10,000 fish 3= less than 100,000 fish 4= less than 1,000,000 fish 5= less than 10,000,000 fish 6= over 10,000,000 fish	
Human Footprint	Categorial(1-100); see Appendix	Raster format
Human Influence Index	Categorial (0-64); see Appendix	Raster format
Distance to roads	Meters (1000 m steps)	Raster format- Topographic map to distance
Distance to towns	Meters (1000 m steps)	Raster format- Topographic map to distance
Distance to railways	Meters (1000 m steps)	Raster format- Topographic map to distance
Distance to airways	Meters (1000 m steps)	Raster format- Topographic map to distance

Habitat data such as elevation, slope, aspect, NDVI, ecoregions and vegetation classes were acquired from the U.S. Geological Survey (2010). The Mean Normalized Difference Vegetation Index (NDVI) is an indicator that allows distinguishing between green vegetation and no vegetation. It is widely used to identify vegetated areas and detect green plant canopies in multispectral remote sensing data. The ecoregions map includes datasets from climate parameters, vegetation, surficial geology, topography, lithology, soils, permafrost, hydrography, fire regimes and glaciations, all of which are obtained by different organizations and experts. It subdivides Alaska into 32 ecoregions based on a combination of the hierarchical approach for ecoregion mapping by Bailey (1983) and the integrated approach by Omernick (1987), and then groups them into two higher levels comprised of three and nine ecoregions each.

Table 4: Ecoregions of Alaska (Nowaki et al. 2001)

ID	Ecoregion
0	Bering Taiga
1	Aleutian Meadows
2	Alaska Range Transition
3	Coastal Rainforest
4	Bering Taiga
5	Pacific Mountain Transition
6	Intermontane Boreal
7	Coastal Mountain Transition
8	Bering Tundra

The vegetation map of Alaska was established by Fleming (1997) using the phenology of a vegetation index (AVHRR/NDVI) collected during the 1991 growing season. It is subdivided into 23 classes of which 19 classes are vegetated.

For the climatic parameters, historical temperature and precipitation data as well as future climate scenarios were obtained from the Scenarios Network for Alaska Planning- SNAP (Walsh et al. 2008; http://www.snap.uaf.edu). The outputs for both historical and future datasets had been downscaled from a two-degree resolution to two kilometre resolution for Alaska with the PRISM methodology. The historical datasets are based on Climate Research Unit (CRU) data from 1901-2009 for temperature and 1901-2006 for precipitation. The future projections for Alaska include datasets from 1980-2099 and are derived from five Global Circulation Models used by the Intergovernmental Panel on Climate Change (IPCC). Two of the three IPCC emission scenarios for Alaska were used in this study: A1B is widely applied as a "midrange" scenario, A2 assumes higher emissions and is considered to be more pessimistic, but probably also more realistic, leaving the A1B scenario as the one which underestimates (e.g. Richardson et al. 2009).

The distances to rivers, coast and lakes were obtained from the coast, river, and lake-shapefile (see Appendix 1.1) and calculated in 1000 m steps. The river layer had to be created by merging two shapefiles, one including all small rivers (lines) and one covering the big rivers (polygons).

Fires after 1950 were summarized by decade and implemented as presence/absence categories for each decade. Wildfires play an important role in a brown bear´s environment and may affect habitat suitability through impacts such as altered food resources.

Salmon data was used to represent food availability and quality in parts of the study area. Distribution for Chinook, Steelhead, Pink, Chum, Sockeye, and Coho as well as abundance for Chinook, Pink, Chum, Sockeye, and Coho salmon was downloaded from the State of the Salmon webpage which is a joint program of the *Wild Salmon Centre* and *Ecotrust* in cooperation with public, tribal, and private organizations around the Pacific Rim. Whereas distribution data for Alaska is comprehensive, abundance data is based on raw estimates from catches and does not cover the whole State. The harvest data from Byerly, Brooks et al. (1999) of the years 1920-1997 was used in order to calculate long-term average harvests. The salmon stocks of western Alaska, though, were not fully exploited until after Alaska attained statehood, therefore a 60% exploitation rate was used. The occurring gaps in the abundance data were defined as one special category (see Table 3) when building the TreeNet model.

The human influence index (HII) and human footprint (HF) were applied to demonstrate correlations with human activities and disturbances and their influence on the ecosystems. The calculation of both indices was developed by Sanderson et al. (2002) and acquired from "The Last of the Wild" (2005) on http://sedac.ciesin.columbia.edu/wildareas/downloads.jsp.

The HII is produced by an overlay of different layers representing the location of various factors (human population distribution, urban areas, roads, navigable rivers and agricultural land uses) whose combination is supposed to exert an influence on ecosystems. It is calculated by adding the influence scores of all these eight input variables. It results in values ranging from 0 (no human influence) to 64 (maximum human influence possible under the method).

The Human footprint is created by normalizing the Human Influence Index by global biomes. Its value ranges from 1 to 100, with 1 indicating that the grid cell is part of the 1% least influenced "wildest" area in its biome (SEDAC 2010). In addition, human influence was also described by distance to roads, railways and towns, calculated in 1000 meter steps (see Appendix 1.1).

2.3 GIS

ArcGIS 9.3 (ESRI ArcMap 9.3, www.esri.com) was used for the Geographic Information processing. At first the exact projection of each environmental variable shapefile needed to be defined in order to change it into one single projection for all variables and for the whole area. In this study, the Alaska Albers NAD1983 state projection was used for reasons of accuracy with respect to the area of interest as it is considered the most Alaska centric. The ArcMap analysis tools were applied to clip some of the shapefiles with the Alaskan coastline and afterwards they were converted into raster files which were then overlaid.

Based on the resulting layer, a regular point lattice layer was created using the Hawths Analysis Tools for ArcGIS 9.3 (Beyer 2004). A 1 km resolution was chosen despite the high amount of data involved and the increased time for calculations needed in order to make the map more accurate and obtain as much information as possible. The point lattice layer thus had a grid size of 1 km which implies a total amount of 1,415,358 measuring points for terrestrial Alaska. The borders of the 12 selected study areas surveyed by Miller et al. (1997) were marked**,** converted into a shapefile and georeferenced. Afterwards each area was correlated with the density data and the lattice layer was clipped with the study areas. Density per square kilometer was computed from the described population estimates (Miller et al. 1997).

2.4 TreeNet

The data mining and machine learning program TreeNet by Salford Systems (http://salford-systems.com/products/treenet.html) was used as the actual model algorithm. It is an instrument of data mining proposed by Friedman in 1999 which makes use of stochastic gradient boosting by applying a decision tree learning algorithm. It fits a series of models, each having a low error rate, and combines them into an ensemble with an increasingly better performance as the series continues. The final model can thus presume most advantages of tree-based models, while overcoming the main disadvantages such as inaccuracy.

Among the most important features of the TreeNet models are an ability for automatic variable subset selection, fast and convenient application, the ability to handle data without pre-processing, resistance to outliers, an automatic handling of missing values and robustness to “noisy” and partially inaccurate data (Elish and Elish 2009, Salford Systems 2010).

Since the model is principally complex, its meaning is demonstrated through a number of special reports, including a ranking of the variables in order of importance, and graphs illustrating the relationship between inputs and outputs.

TreeNet has already been successfully applied by Graeber (2006) to model brown bear densities in the Pacific Rim. In this study, the 36 input variables of the lattice layer for the 12 Miller study areas were used in different combinations and based on different settings to build the basic density model. The bear density estimates in the study areas represent the target variable. The best model was selected based on accuracy of the prediction represented by the deviation of the predicted density from the Miller estimate "GB_dens", and moreover through gains chart created by TreeNet. The most important variables of this model were then chosen to build a more detailed model. This model was again handled in the same way and a final model was produced. This final ranking of variable importance formed the base for the scoring for the whole of Alaska and was visualized in ArcGIS as an Alaska-wide predictive brown bear density map.

Table 5: Model setting details

ABECO610	without salmon data and without fire data, with 6 nodes and 10 observations at final node
ABECO20	without salmon data and without fire data, with 20 nodes and 30 observations at final node
All215	with all variables with two nodes and 15 observations at final node
all610	with all variables with 6 nodes and 10 observations at final node
all2030	with all variables with 20 nodes and 30 observations at final node
cat215	without categorical variables with two nodes and 15 observations at final node
cat610	without categorical variables, with 6 nodes and 10 observations at final node
cat2030	without categorical variables, with 20 nodes and 30 observations at final node
strong215	best scoring of the "all variables" model with two nodes and 15 observations at final node
strong610	best scoring of the "all variables" model, with 6 nodes and 10 observations at final node
strong2030	best scoring of the "all variables" model, with 20 nodes and 30 observations at final node
supersuper	created out of the variable scoring of the "strong" model (standard settings)
ABECO2_15	without salmon data and without fire data, with two nodes and 15 observations at final node
AB2030Auto	with fire and salmon ab., with 20 nodes and 30 observations at final node,auto learning rate

AB0215001	with fire and salmon ab., with two nodes, 15 observations at final node, learning rate 0.01
AB61001	with fire and salmon ab., with 6 nodes and 10 observations at final node, learning rate 0.01
GB_Dens	Brown bear density estimates by Miller et al. (1997)

An additional model based on climate data only was established and compared to the best derived model for predicting brown density bear estimates. The deviation of the climate-only model was low and it was subsequently used as a base for predicting bear density into the future: the 24 future climate variables for the A1B and A2 scenario were applied and the results were scored (Murphy et al. 2010, SNAP 2010).

2.5 Accuracy assessment

In order to evaluate the accuracy of the bear density model, a known estimated value (0.0288 bears per km^2) for a specific area (GMU 13 A, see Figure 9) (Testa et al. 1998) was compared to the estimated density for that area. This GMU was chosen because data and estimates were obtained with the same methods (CMR) as the Miller estimates. The game management unit 13 A was clipped out of the lattice layer. 11,339 data points were received and the mean was taken to compare it with the reported density data (28.8 bears per 1000 km^2).

2.6 Ground truthing

A ground truthing survey was conducted to obtain comparative data for evaluating the density model. Therefore, a line transect along the Yukon River between Eagle and Circle through the Yukon-Charley Rivers National Preserve was studied between 27th and 31st of May 2009. The first part of the survey concentrated on direct bear sightings. Both river banks were regularly observed with binoculars and detected bears were counted. The average visibility to each side of the river was defined as 20 meters, resulting in a total area observed of 10.6 km^2.

k = number of lines = 2

L = total line length = 265 km x2 = 530 km

w = strip width = 0.02 km

a = area of region covered = w*L = 0,02 km x 530 km = 10.6 km²

The second part involved the observation of bear tracks. 12 georeferenced sample plots of 5 x 5 meters each were examined along the transect in order to obtain presence/absence data for bear tracks.

In order to compare the predicted density and the Yukon section surveyed, the section was buffered with 20 meters on each site. Afterwards the lattice layer was clipped with the section. 338 data points were obtained and the mean value was detected.

2.7 Marxan

When working with systematic conservation planning, explicit targets for biodiversity features need to be identified in order to support decisions on which landscape should be protected to achieve these targets (Possingham et al. 2000). Marxan conservation planning software has the goal of detecting reserve systems that, in equal measure, meet biodiversity targets, minimize costs and address objectives of spatial design (Ball and Possingham 2000). Therefore it minimizes the value of an objective function, which is a combination of cost (1) of each potential reserve and a penalty (5) for any unmet biodiversity target:

$$\sum_{PUs} Cost^{1} + BLM^{2} \sum_{PUs} Boundary^{3} + \sum_{ConValue} SPF^{4} x Penalty^{5} + CostThresholdPenalty(t)^{6}$$

Equation 1

The penalty factor (4) adjusts the emphasis on meeting a target while the boundary length modifier (2) maximizes compactness by evaluating how much emphasis should be placed on minimizing the overall reserve system boundary length (3) (Ball and Possingham 2000).

Marxan uses a simulated annealing algorithm to improve the value of the whole reserve system by testing different selections of units and thus offers several good, near-optimal solutions instead of a single exact one (Possingham et al. 2000). Every planning unit is related to a cost value which is calculated as an economic cost, a simple reflection of the area or an ecological value.

In this study, the amount and location of protected area for the conservation of 15% of all the Alaskan brown bear population, as well as for 15% of the area of Alaska, are determined. Furthermore, the extent to which it is already existing in reserves and National Parks is evaluated with regards to the proposed protected areas by overlaying these layers. For calculating the optimal brown bear conservation areas, a raster grid with pixel sizes of 6 km^2 was created.

The approach used in this study takes two different theoretical considerations into account:

- The implementation of a conservation area near urban settlement would be expensive, because the areas are in multiple use by humans and thus expensive to obtain and convert into conservation areas.

- A conservation area near human activity would have a negative influence on the bear population according to this study (see TreeNet results and e.g. Horn et al. 2009).

Out of these theoretical considerations, a cost function was built for Marxan (Equation 2). The TreeNet results offer a detailed partial dependence of the input variables. The negative partial dependence of the variables that describe human influence was taken to develop the costs. Therefore, the distances to towns, roads, railways and airports were calculated and defined as 1 where the partial dependence for the bear population was negative. If the partial dependence was positive, the costs were defined as 0.

The cost function is consequently a simple addition of the negative partial dependence of the variables that describe human influence:

$$Cost = \sum a + b + c + d$$

Equation 2

a= variable threshold cost for distance to roads

b= variable threshold cost for distance to towns
c= variable threshold cost for distance to railways
d= variable threshold cost for distance to airport runways

The highest costs can be found where two or three variables with negative human influence on the bear population are overlapping, thus indicating areas of conflict.

Table 6: Selected variables and their range of positive and negative partial dependence

Variable Name	Positive partial dependence	Negative partial dependence
Mean temperature in December during the decade 2000-2009	-10 to 0℃	-24 to -10℃
Distance to roads	from 70 km onwards	0-70 km
Distance to airstrips	87 km to 160 km	0-87 km and 160-300 km
Distance to coast	0-150 km	150 -300 km
Distance to railway	0-75 km; 100- 550km; 620-700km	75-100 km; 550-620km
Mean temperature in June during the decade 2000-2009	4.5-11℃	11- 14.5℃
Distance to towns	0-70 km	70-150 km

3 Results

3.1 TreeNet Data Mining Model

Different TreeNet configurations were tested with every model and in several combinations of 20 nodes and 30 observations per node, as well as two nodes and 15 observations on the final node. The learning rate was also varied, the performance degraded when applying a learning rate of 0.01. The best models were obtained using the Auto learning rate.

Out of all the models created, the best overall model was selected, by choosing the model with the smallest deviation from the Miller study area (see Appendix 1, Table I). The higher scored variables of this model (All2030, All615, All215) were used to run a new model (called “strong”), of which again the variables ranked highest were selected for the final model. This is not common practice, but decreased the error of the model in this case. It has to be taken in account, that even in the model with all variables, only a small amount of variables was ranked high by TreeNet, leaving the other variables with a scoring of under 0.01. This final model seemed to display the best performance so far. It has a very low deviation from the original estimates of the Miller study areas. Moreover, the whole results seem to be robust, the mean squared error is very low and no negative values occur (Figure 12).

Out of a model including all environmental variables, the final model containing only the most important variables was not only chosen because of its low deviation from the original estimates, but also due to its overall performance.

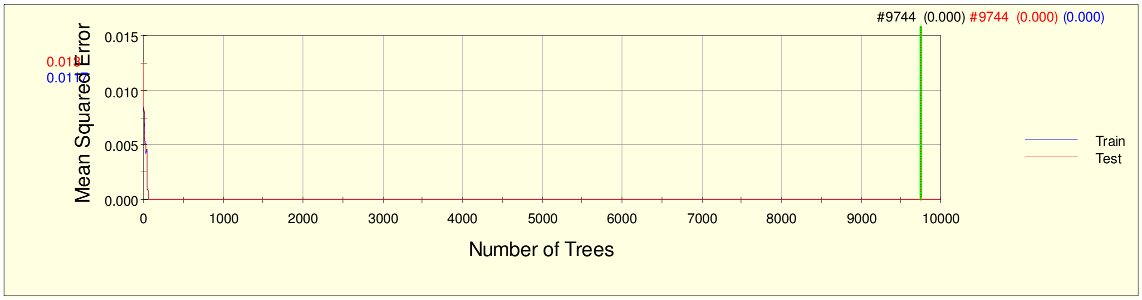

Figure 12: Mean squared error with optimal number of trees (9744 trees)

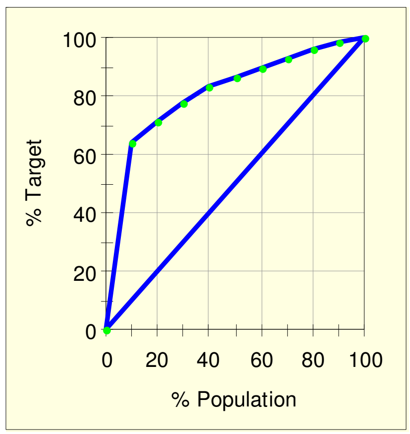

Figure 13: Gains

Table 7: TreeNet Gains Data

Bin	Target Bin Avg.	Target in Bin	Cum % Target in Bin	Cum% POP	% POP	Cases in Bin	Cum lift	Lift Pop
1	0.341	63.74	63.74	9.50	9.50	2,613	6.71	6.71
2	0.038	7.52	71.25	19.50	10.00	2,750	3.65	0.75
3	0.029	6.06	77.31	30.00	10.50	2,887	2.58	0.58
4	0.028	5.53	82.84	40.00	10.00	2,751	2.07	0.55
5	0.018	3.62	86.46	50.00	10.00	2,750	1.73	0.36
6	0.016	3.15	89.61	60.00	10.00	2,749	1.49	0.32
7	0.016	3.16	92.77	70.01	10.02	2,755	1.32	0.32
8	0.016	3.15	95.91	80.00	9.99	2,747	1.20	0.32
9	0.014	2.67	98.58	90.00	10.00	2,750	1.10	0.27
10	0.007	1.42	100.00	100.00	10.00	2,750	1.00	0.14

The gains chart (Figure 13 and Table 7) shows that app. 84 % of the brown bear density is properly predicted. This presents the best predictive density model for Alaska, to date.

Table 8: Ranking of variable importance

<table>
<tr><th>Variable</th><th>Acronym</th><th>Score</th><th></th></tr>
<tr><td>Ecoregions 2</td><td>ECO2</td><td>100.00</td><td>|||||||||||||||||||||||||||||||||||||||||</td></tr>
<tr><td>Mean annual temperature December</td><td>T1200N</td><td>49.58</td><td>||||||||||||||||||||</td></tr>
<tr><td>Abundance pink salmon</td><td>AB_PINK</td><td>39.97</td><td>||||||||||||||||</td></tr>
<tr><td>Distancetoroads</td><td>ROADS</td><td>24.01</td><td>|||||||||</td></tr>
<tr><td>Distancetoairstrips</td><td>AIRRWY</td><td>21.84</td><td>||||||||</td></tr>
<tr><td>Distancetocoast</td><td>COASTDI</td><td>19.10</td><td>|||||||</td></tr>
<tr><td>Distancetorailway</td><td>DISTTRA</td><td>15.17</td><td>||||||</td></tr>
<tr><td>Meanannualtemperature June</td><td>T600N</td><td>13.77</td><td>|||||</td></tr>
<tr><td>Distribution sockeysalmon</td><td>DB_SOCK</td><td>12.23</td><td>||||</td></tr>
<tr><td>Distribution chinooksalmon</td><td>DB_CHIN</td><td>12.09</td><td>||||</td></tr>
<tr><td>DIstancetotowns</td><td>EUCDIST</td><td>10.96</td><td>||||</td></tr>
<tr><td>Abundancesockeyesalmon</td><td>AB_SOCK</td><td>9.94</td><td>|||</td></tr>
<tr><td>Distribution cohosalmon</td><td>DB_COHO</td><td>0.06</td><td></td></tr>
</table>

The importance of the variables is demonstrated by the internal score of TreeNet, where the highest importance always equals the value 100 (in relative terms). In this model, ecoregions 2 are ranked most important, followed by mean temperature in December and the abundance of pink salmon (Table 8). This was also supported by the 22 other models that were run (details not shown).The decrease of the scoring form the first to the second variable is about 50%, which emphasizes the importance of the ecoregion predictor. Other variables seem to be of lower importance and somewhat interacting. Worthwhile to mention is the bigger set of predictors that deals with human impacts.

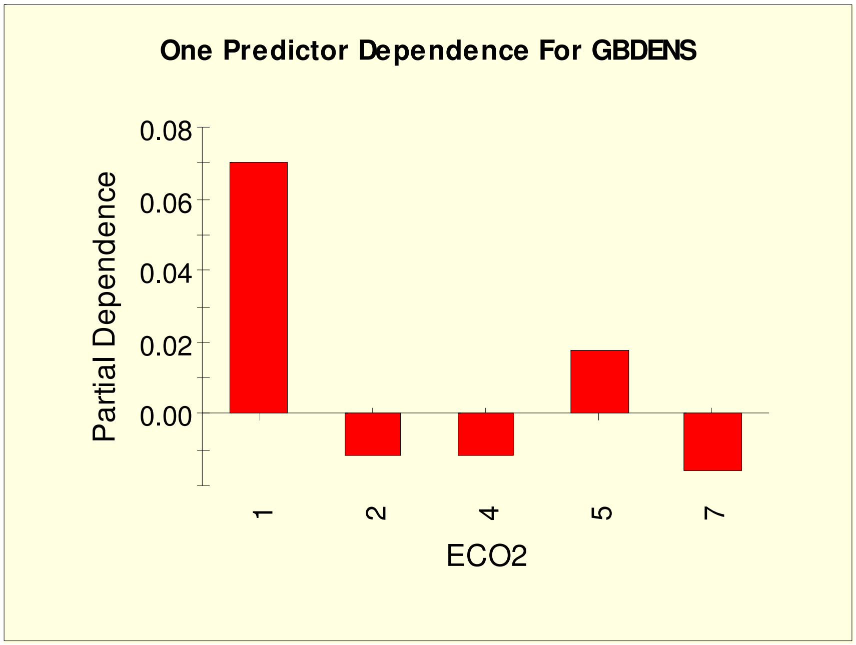

Figure 14: Partial dependence for ecoregions 2

Ecoregion 1 and 5 (Aleutian Meadows and Pacific Mountain Transition) seem to have positive influence, while ecoregions 2, 4, and 7 (Alaska Range Transition, Bering Taiga, and Coastal Mountain Transition) have a low negative influence on bear densities (Figure 14).

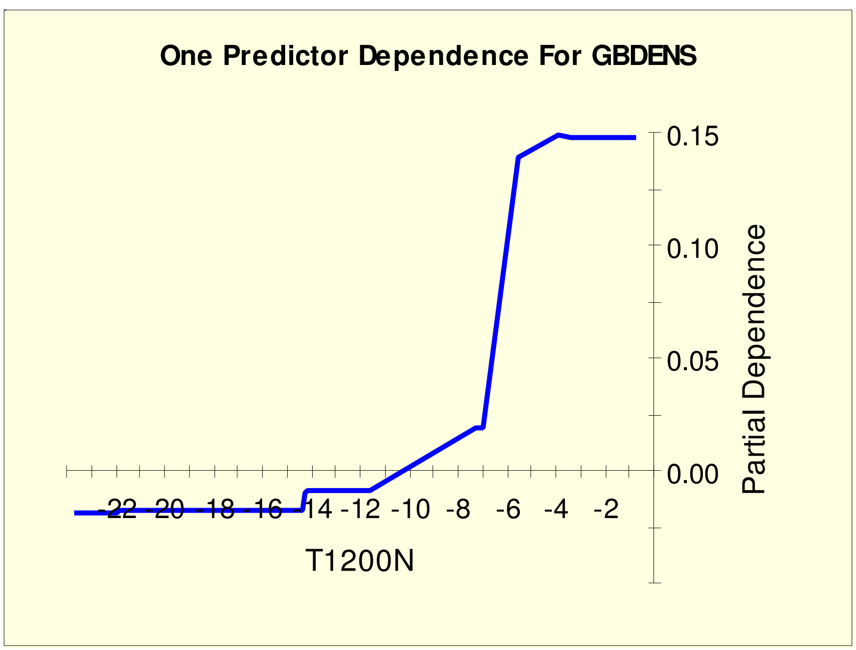

Figure 15: Partial dependence for mean annual temperature in December (2000-2009)

Figure 15 shows a clear threshold, December temperature has a positive effect when being warmer than – 10°C.

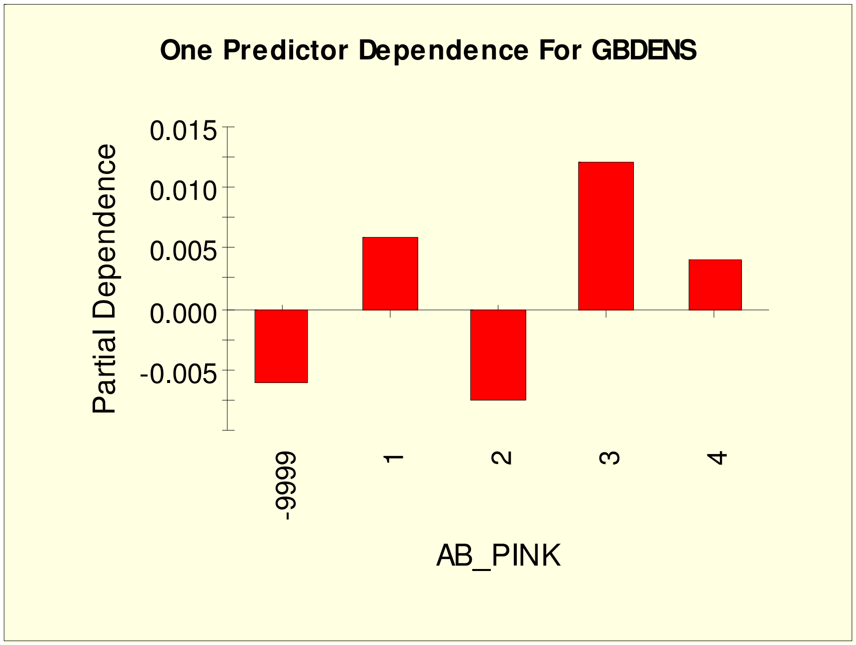

Figure 16: Partial dependence of pink salmon abundance in ranked abundance classes (9999= N.A. or not present; 1= less than 1,000 fish; 2= less than 10,000 fish; 3= less than 100,000 fish; 4= less than 1,000,000 fish

A higher abundance of pink salmon seems to have a positive impact on brown bear density. The category "-9999" includes areas where no data was available (Figure 16). However in these areas pink is mostly not present at all, which subsequently may support the negative effect.

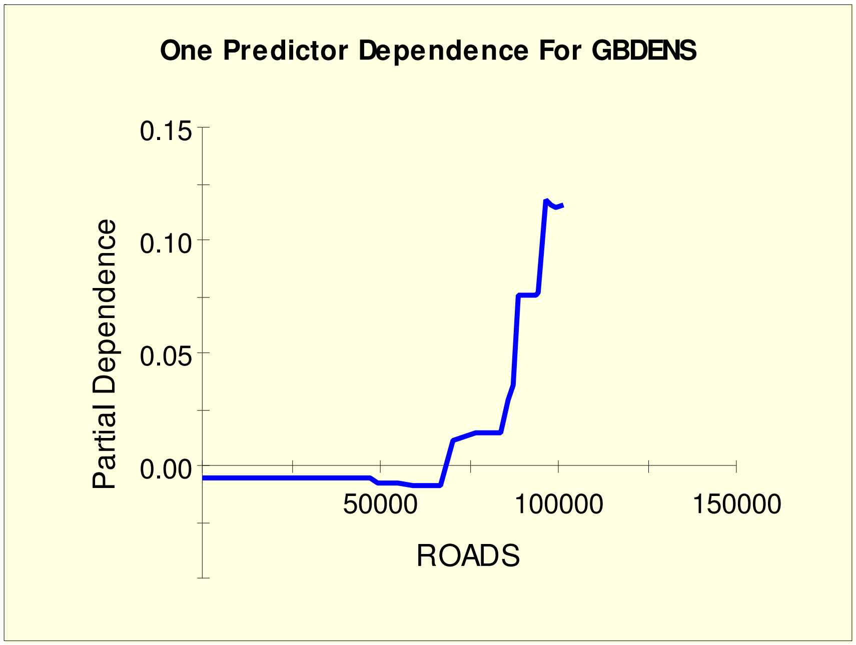

Figure 17: Partial dependence for “distance to roads” (in meters)

On an Alaska-scale, roads demonstrate a negative effect on brown bear density until up to app. 70 km distance (Figure 17).

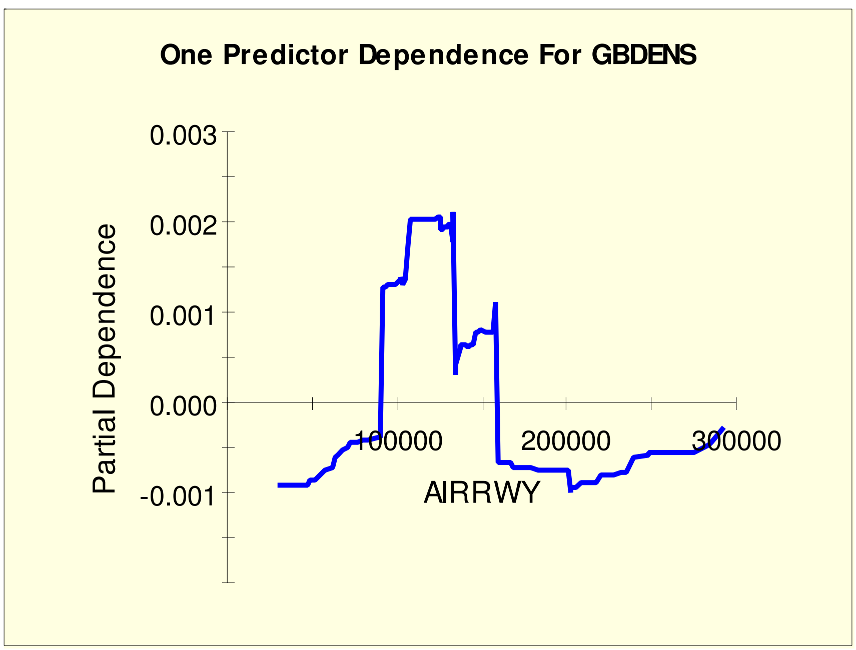

Figure 18: Partial dependence for “distance to airstrips” in meters

Figure 18 indicates a negative impact on brown bear density within the first 80 -160 km of distance from airstrips. Most of the other models demonstrated the same threshold, but the partial dependence remained negative afterwards (Appendix 1, Figure I).

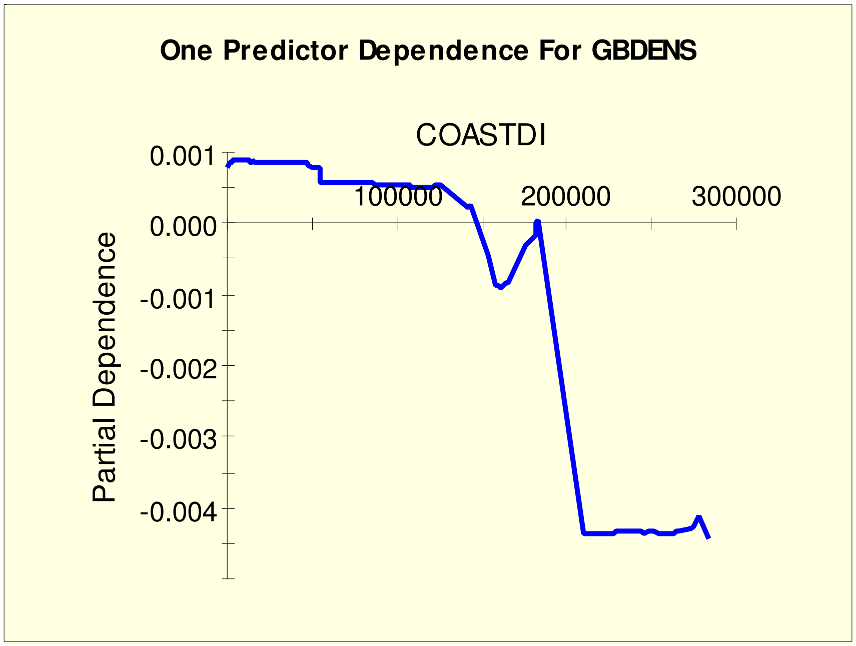

Figure 19: Partial dependence for “distance to coast”

The obvious negative effect of an increasing distance to the coast can probably be explained by the correlation of “distance to coast” and food availability in form of salmon (Figure 19).

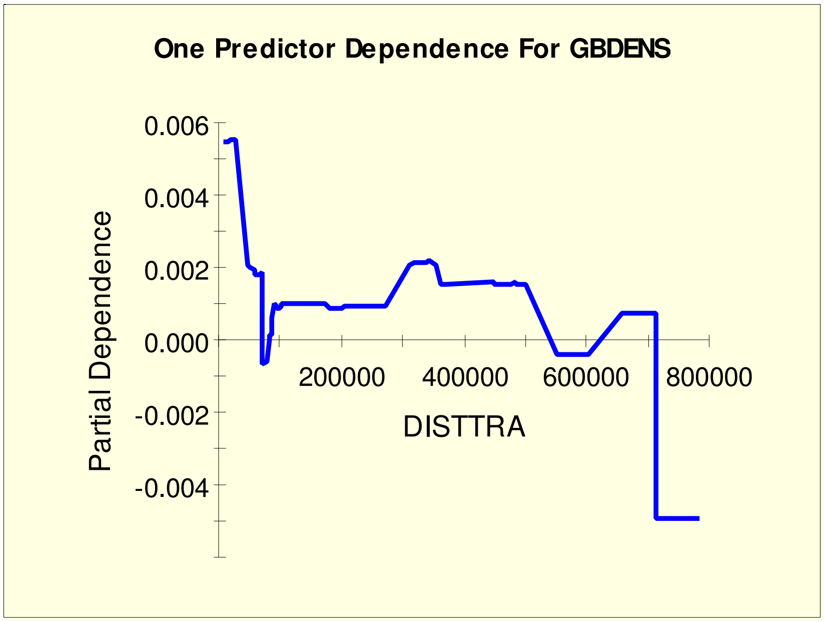

Figure 20: Partial dependence for “distance to railway” (in meters)

According to Figure 20, a reduced distance to railways seems to influence bear density positively. This overall result was similar in most other models, even if the curve had a slightly altered shape. Three sections can be identified: Bear densities are high in the first 20 km, slightly drop and stay lower until 700 km and then drop entirely.

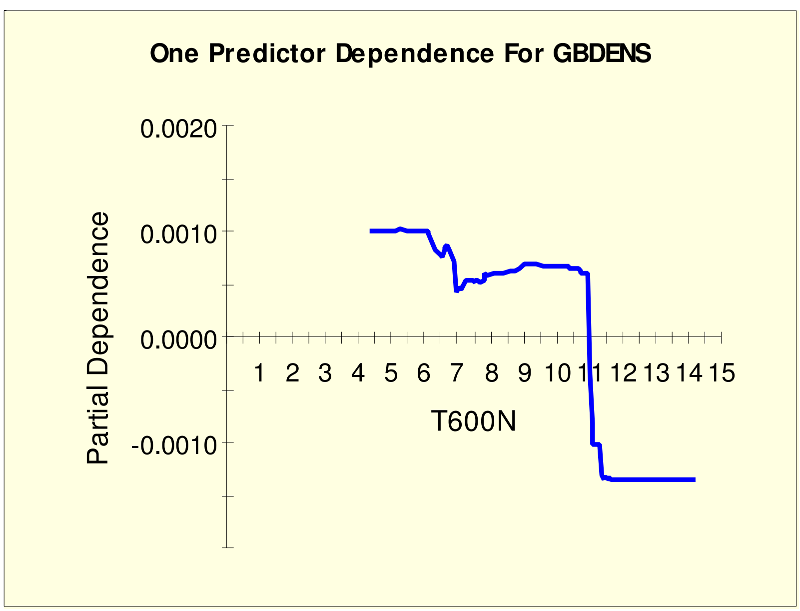

Figure 21: Partial dependence for mean annual temperature (in °C) in June (2000-2009)

An average summer temperature over 11 °C seems to have a negative impact on brown bear density (Figure 21).

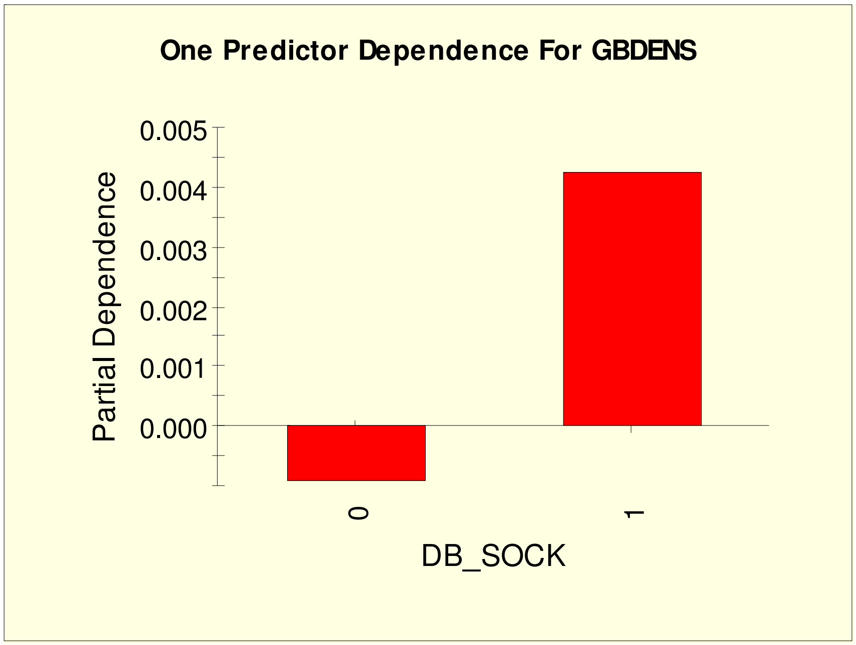

Figure 22: Partial dependence of sockeye salmon distribution

Figure 22 implies a positive influence of sockeye salmon presence on bears.

According to the TreeNet scoring, the four variables ranked the lowest had not much influence on brown bear density. For some, the performance is not very clear, for instance the negative influence of chinook salmon presence on bear abundance (Figure 23).

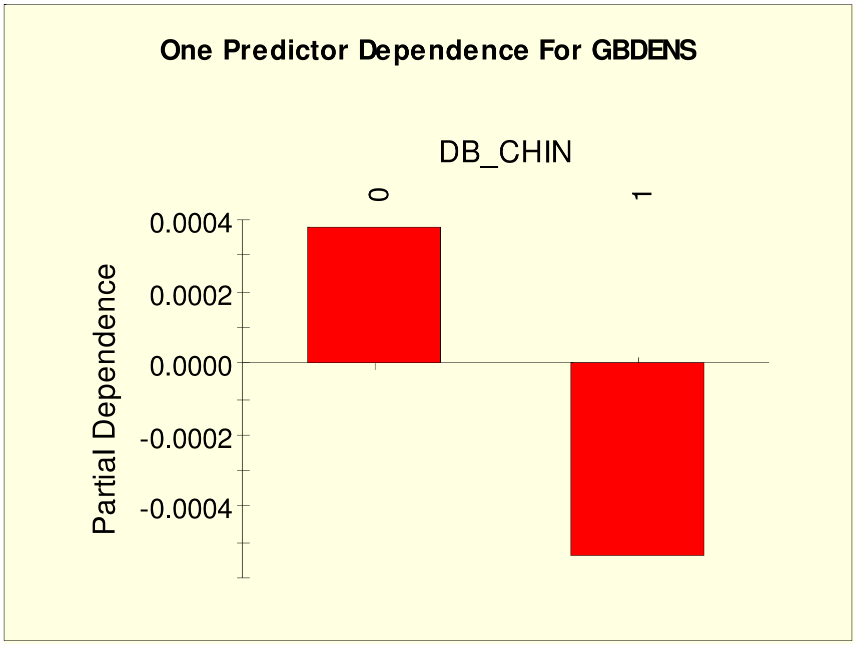

Figure 23: Partial dependence of chinook salmon distribution

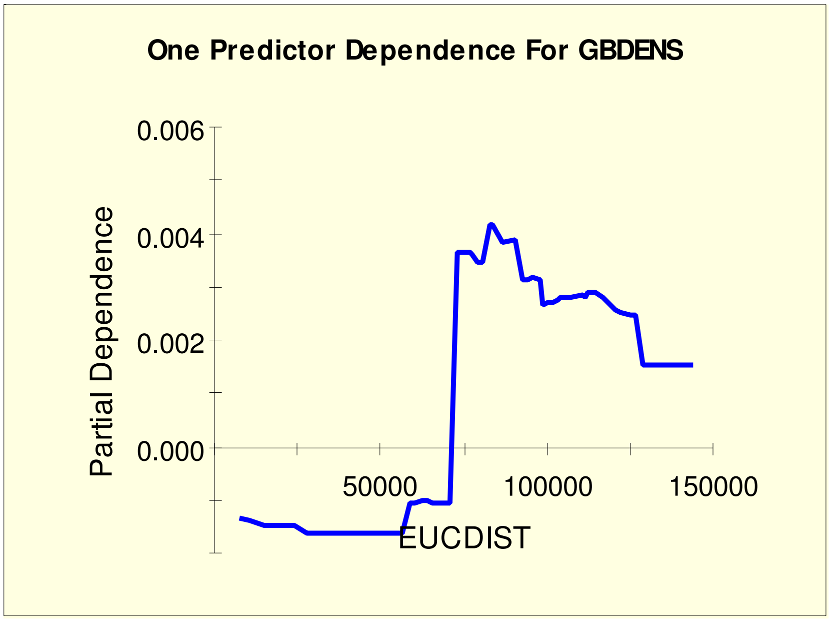

Figure 24: Partial dependence for "distance to towns"

Figure 24 shows a clear threshold with negative influence of towns on brown bear density within the 75 km of distance.

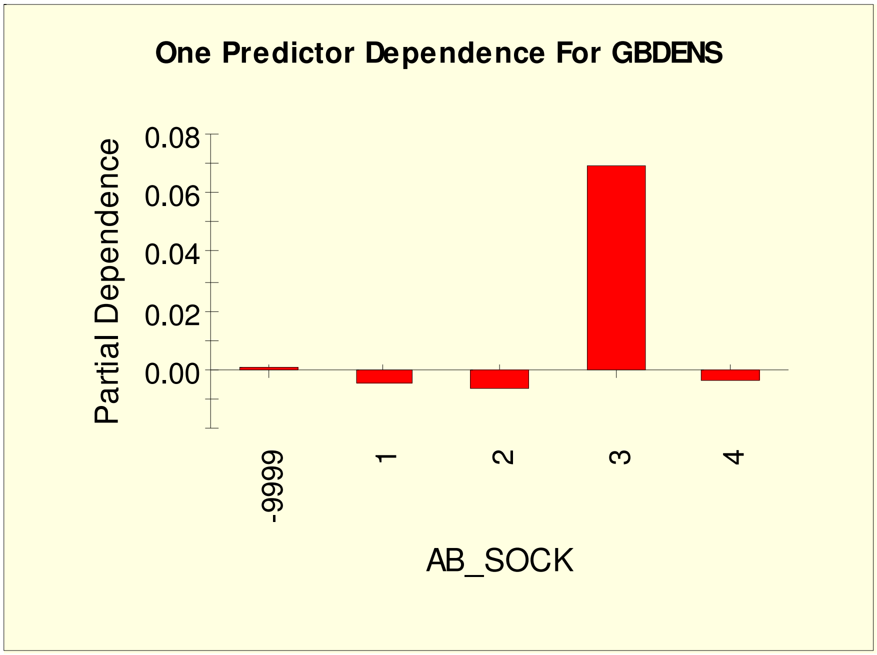

Figure 25: Partial dependence for sockeye salmon abundance

Abundance class 3 has a positive effect on bear density, the units on the y-axis are very small indicating that the other abundance classes has almost no negative influence (Figure 25).

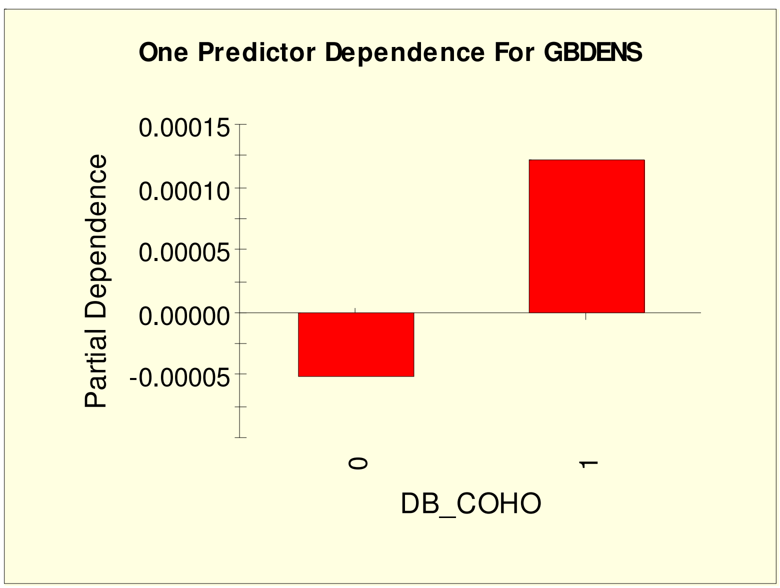

Figure 26: Partial dependence for coho salmon distribution

According to Figure 26, coho salmon has a positive impact on brown bear abundance where it occurs.

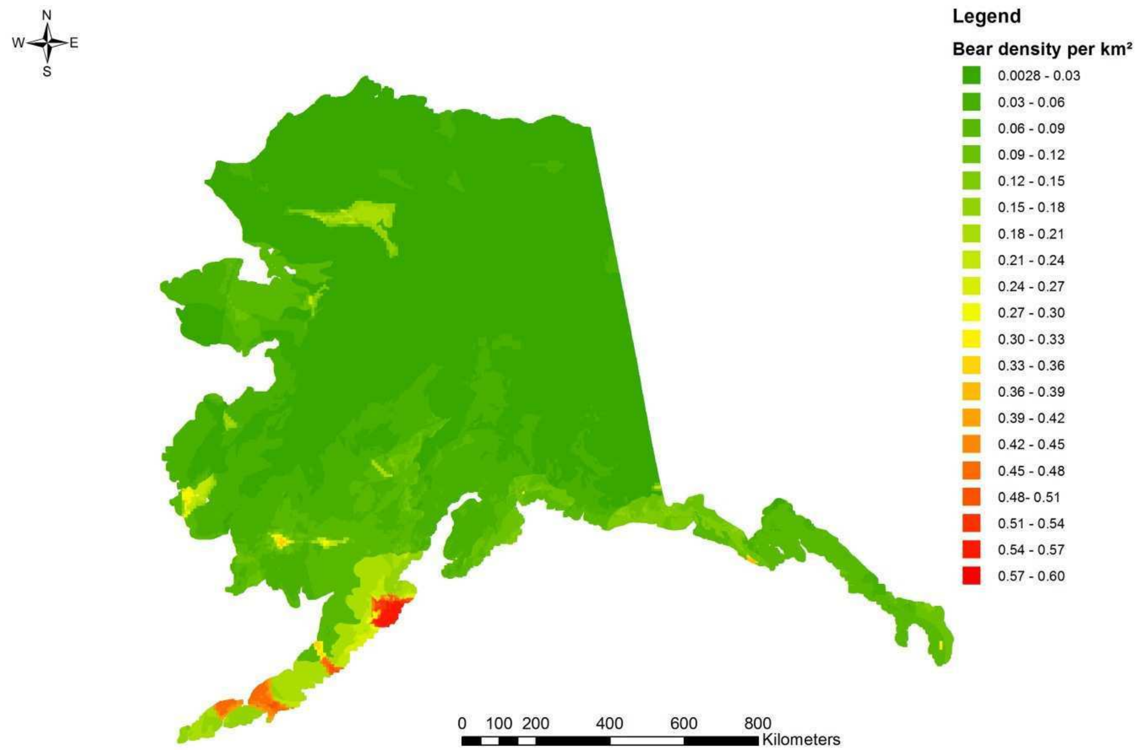

Figure 27: Predicted bear densities (bears per km²) for terrestrial Alaska in 2010

In accordance with the extrapolation of Miller et al. (1997), the main habitat of brown bears can be found in the south of Alaska, with highest densities (up to 0.6 bears per km²) on the Alaskan Peninsula. Higher densities (around 0.2 bears per km²) can be found up in the north around the Kabuk Valley National Park and the Southwestern coast.

3.2 Accuracy assessment

The estimated 0.028 bears per km² published by Testa et al. (1998) had differed only by 0.00276 from the here predicted 0.02524 bears per km² (see Chapter 2.5) Within the predicted 0.02524 bears per km² of the game management unit the variance was 0.0001 and the standard deviation was 0.0106.

3.3 Ground truthing

No bears were directly observed along the Yukon transect. Bear tracks were recorded on two sampling points. The bear density model predicts a mean density of 0.0165 bears per km² for the Yukon transect. As shown in the map, the predicted densities are very similar around the Yukon transect.

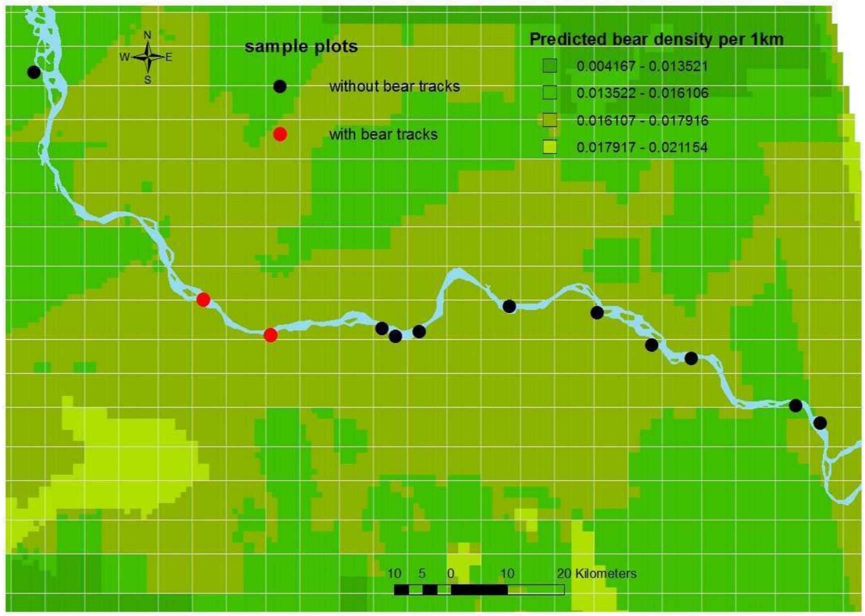

Figure 28: Yukon River transect and sample points underlaid with the predictive bear density map (Fig. 27).

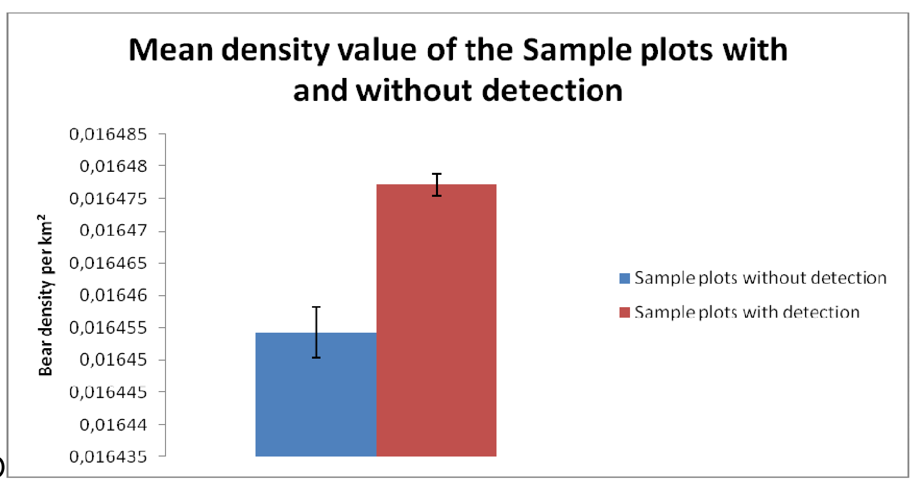

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Figure 29: Mean estimated density value of the sample plots with and without detection of bear tracks with 95% confidence intervals

3.4 Climate projections

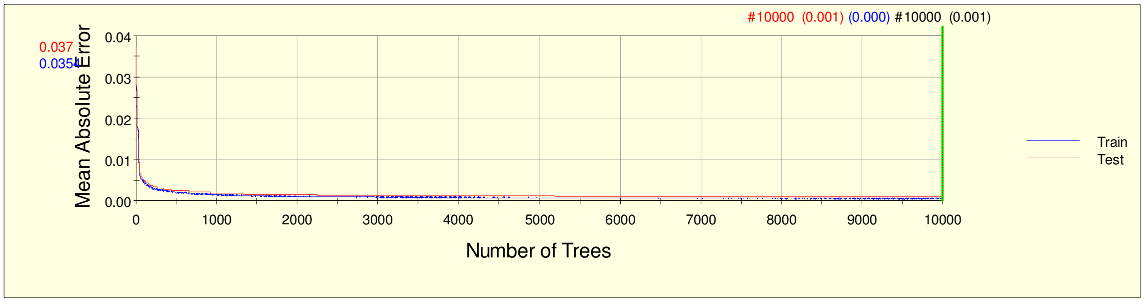

Figure 30: Mean absolute error model based on climate variables only

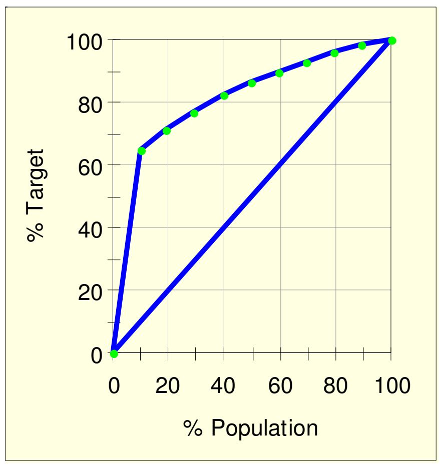

Figure 31: Gains of model based on climate variables only

As shown in Table 8 the winter temperature seems to have the highest influence on the bear density. The accuracy when using only climate decreased to 81 % of population properly predicted by the model, which still can be considered high.

Table 9: Ranking of variable importance

Variable	Score	
T1200N	100,00	|||||||||||||||||||||||||||||||||||||||
P600N	25,41	||||||||||
P1200N	23,93	|||||||||
T600N	21,66	||||||||

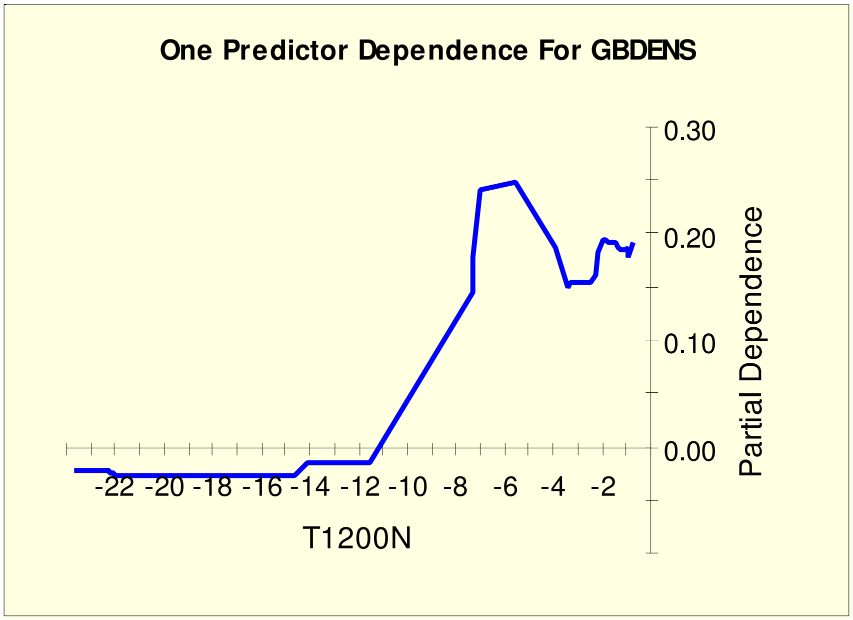

Figure 32: Partial dependence for mean annual temperature in °C in December (2000-2009)

Similar to the results of the density data mining model, the temperature shows negative partial dependence when reaching lower temperatures than -12°C (Figure 32).

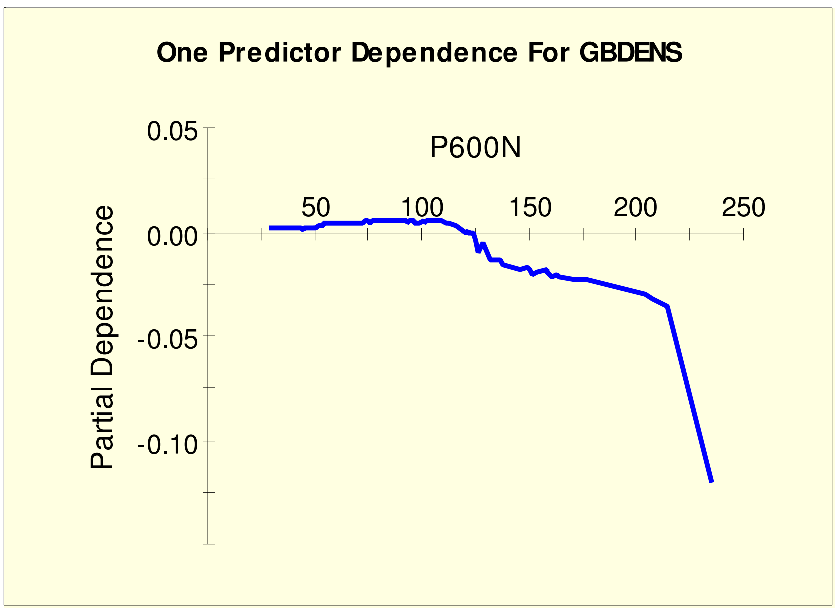

Figure 33: Partial dependence for mean annual precipitation (in millimeter) in June (2000-2009)

According to Figure 33, summer precipitation does not seem to have a significant impact on bear density. The partial dependence has a slightly positive dependence until 150mm. It does not seem to have any important positive influence on bear density, but a strong negative influence from 225mm upwards.

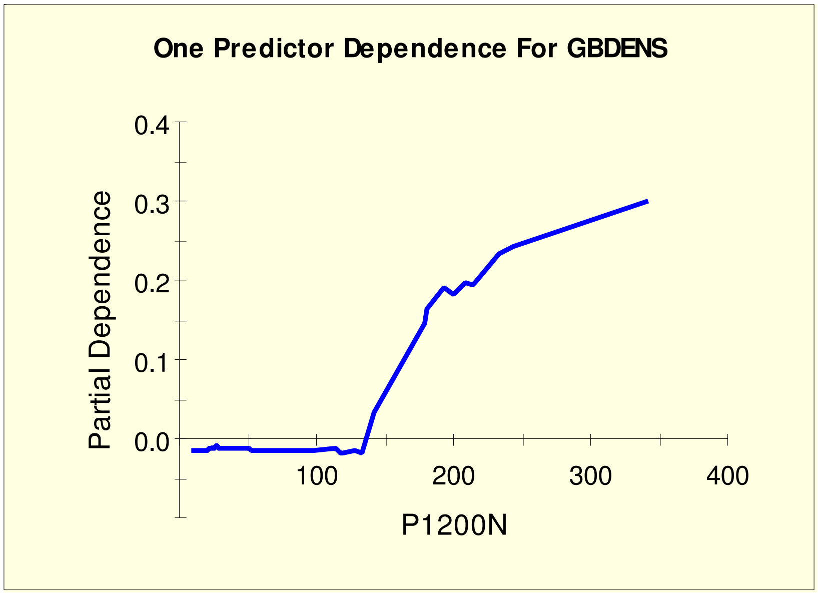

Figure 34: Partial dependence for mean annual precipitation (in millimeters) in December (2000-09)

Winter precipitation has almost no or only a small negative impact on bear density within 0 to 150 mm; higher winter preciptiation seems to have a positive effect (Figure 34).

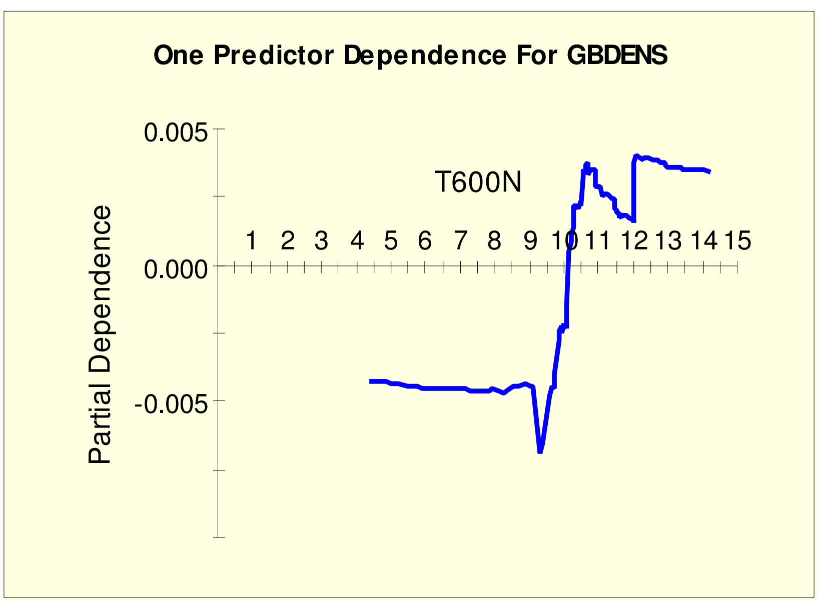

Figure 35: Partial dependence for mean annual tempetarure in °C in June (2000-2009)

Although only small y-units, higher summer temperatures appear to be positive for brown bear density starting from 10℃ upwards (Figure 35). This result is in conflict with the results of the first data mining model, but the y-units are rather small and this variable is ranked as one of the least important one.

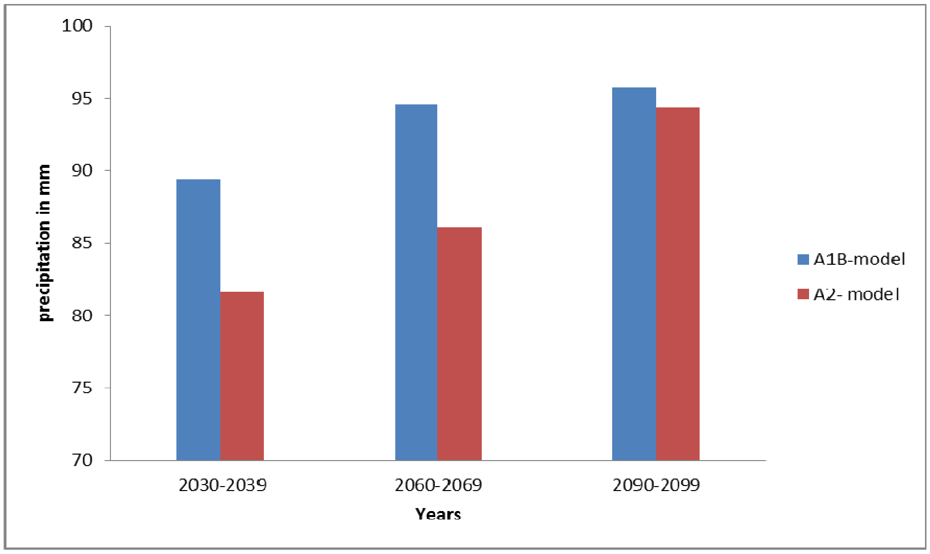

Figure 36: Comparison of mean precipitation in June until 2099 based on A1B and A2 scenario

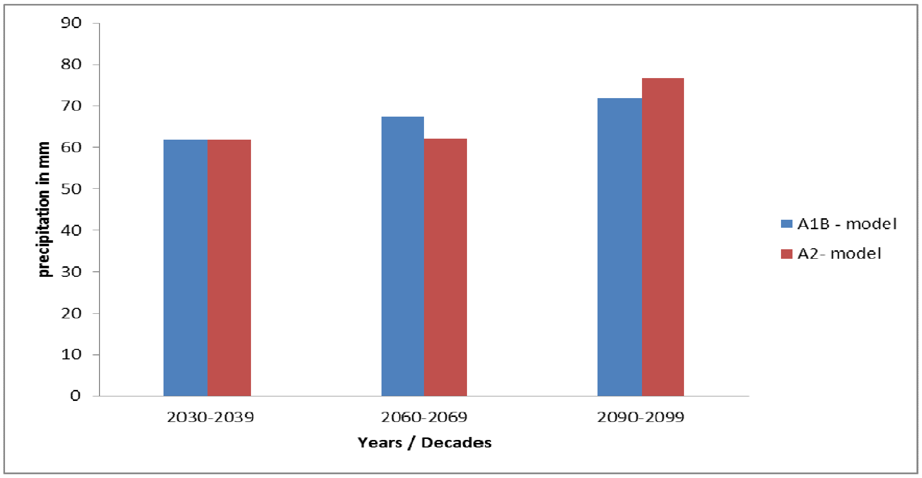

Figure 37: Comparison of mean precipitation in December until 2099 based on A1B and A2 scenario

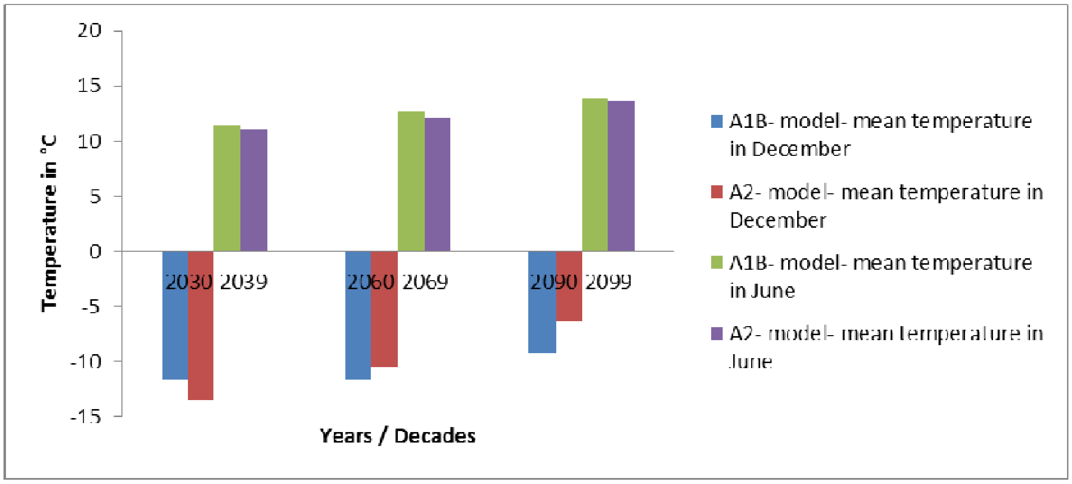

Figure 38: Comparison of mean summer and winter temperatures in °C under scenario A1B and A2 for three decades

Figures 36 to 38 show the predicted winter and summer climates under emission scenario A1B and A2 without standard deviation

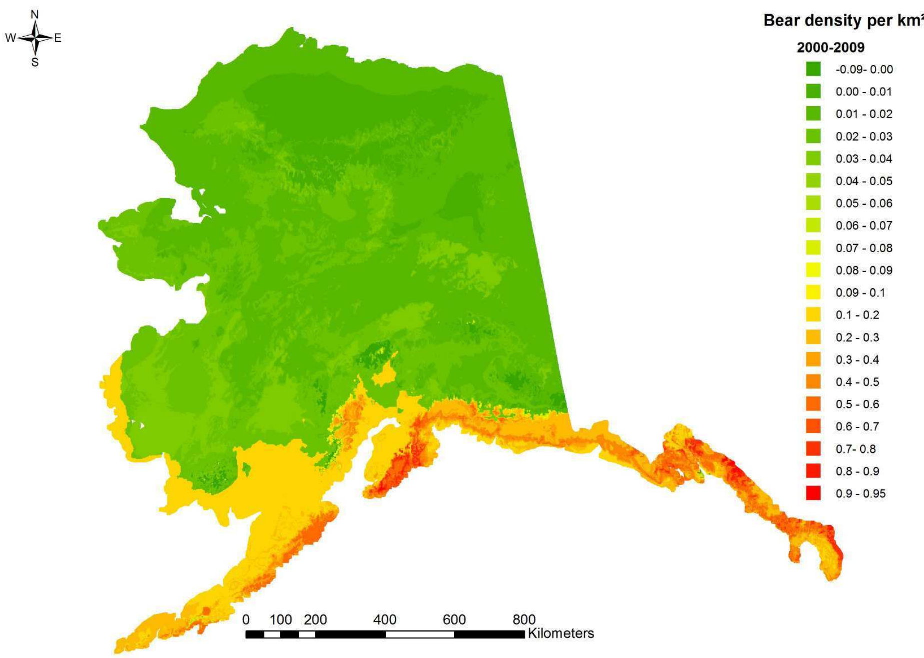

Figure 39: Predicted bear density (bears per km²) for the decade 2000-2009 based on climate variables only

The bear density in the south predicted by the climate-only model is significantly higher than the density estimates derived through the regular model (Figure 27 and 39).

Nevertheless this climate model was chosen because it showed the best overall performance.

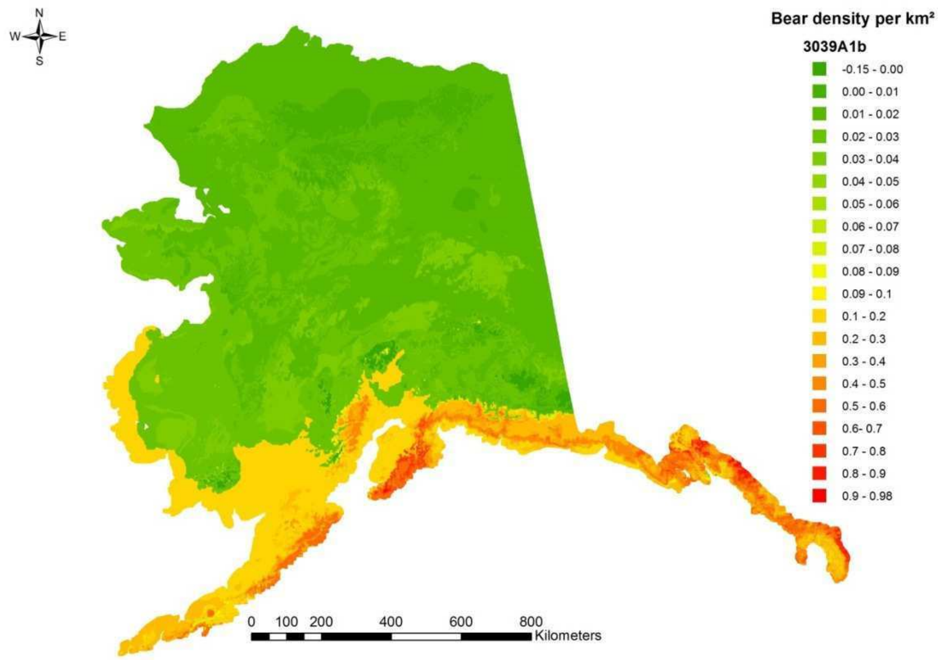

Figure 40: Predicted bear density (bears per km²) for the decade 2030-2039 (scenario A1B)

Small increases of bear density in the south can be detected as well as little improvements of bear habitat along the coast (Figure 40 and 41).

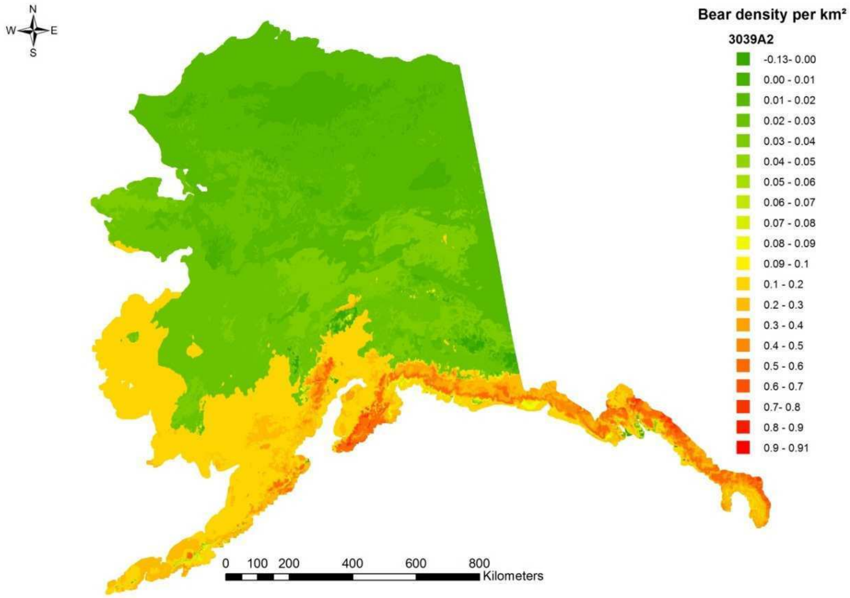

Figure 41: Predicted bear density (bears per km²) for the decade 2030-2039 (emissions scenario A2)

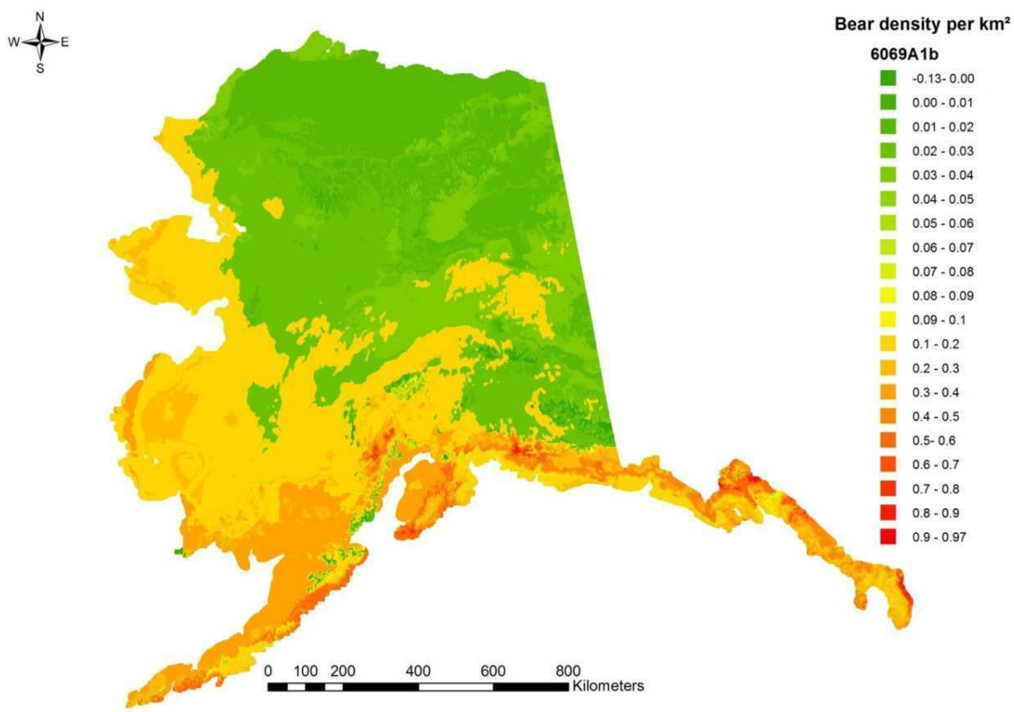

Figure 42: Predicted bear density (bears per km²) for the decade 2060-2069 (emissions scenario A1B)

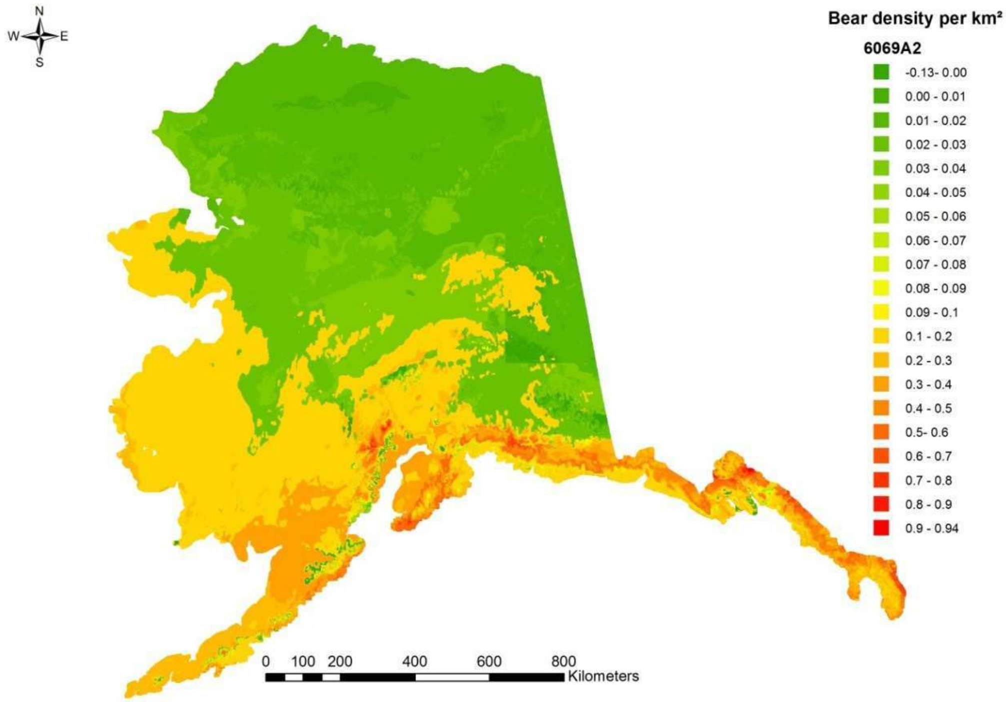

Figure 43: Predicted bear density (bears per km²) for the decade 2060-2069 (emissions scenario A2)

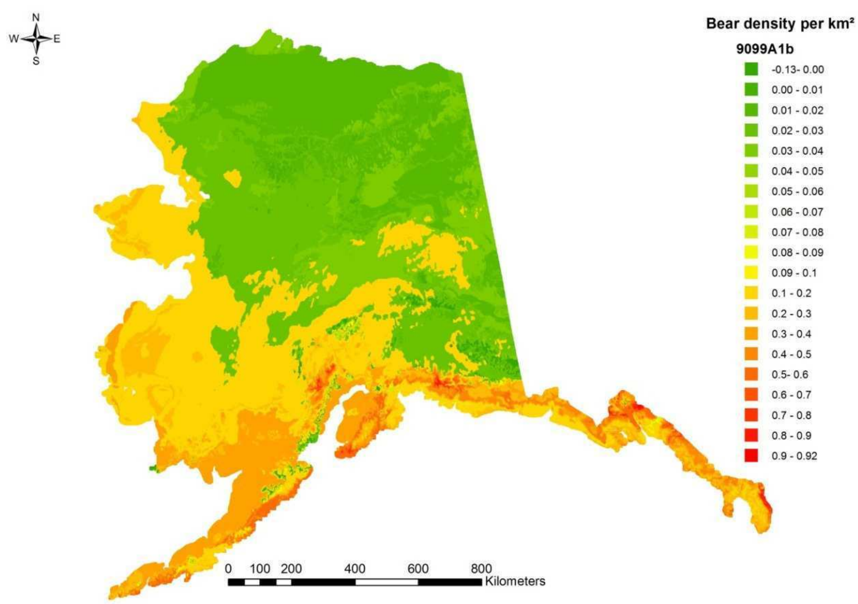

Figure 44: Predicted bear density (bears per km²) for the decade 2090-2099 (emissions scenario A1B)

Figure 44 shows a massive expansion of brown bear density towards the north of Alaska for the years 2060 onwards. Bear numbers seem also to increase in the southern habitats of Alaska in accordance with the models of the decades 2030-39 and 2060-69.

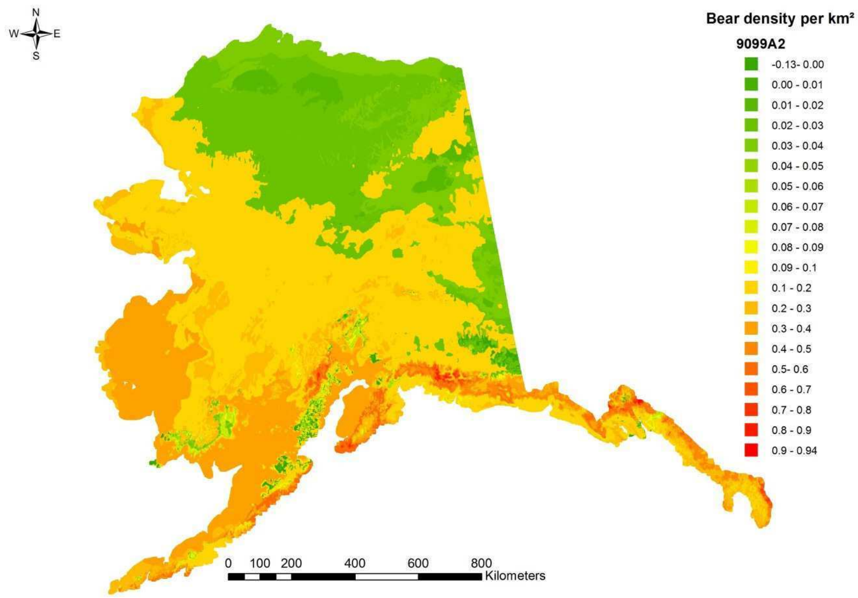

Figure 45: Predicted bear density (bears per km²) for the decade 2090-2099 (emissions scenario A2)

Habitat suitability, the environmental niche using climate data for the bear population seems to increase within the next 100 years. It moves northwards, from the southern areas towards central Alaska. Costal habitat appear to be very suitable for brown bears and show the highest movement towards the north of Alaska. This movement is particularly obvious in the A2 emission scenario-model. Higher bear densities could then be found for the decade 2090-99 in whole Alaska except some small regions in the Brooks Range.

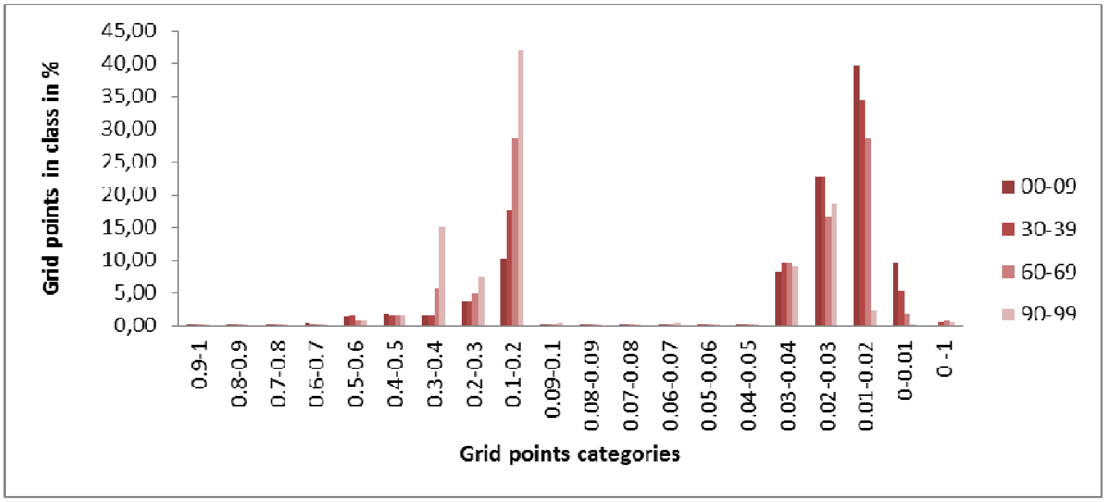

Figure 46: Comparison of grid points in different brown bear density classes based on scenario A2

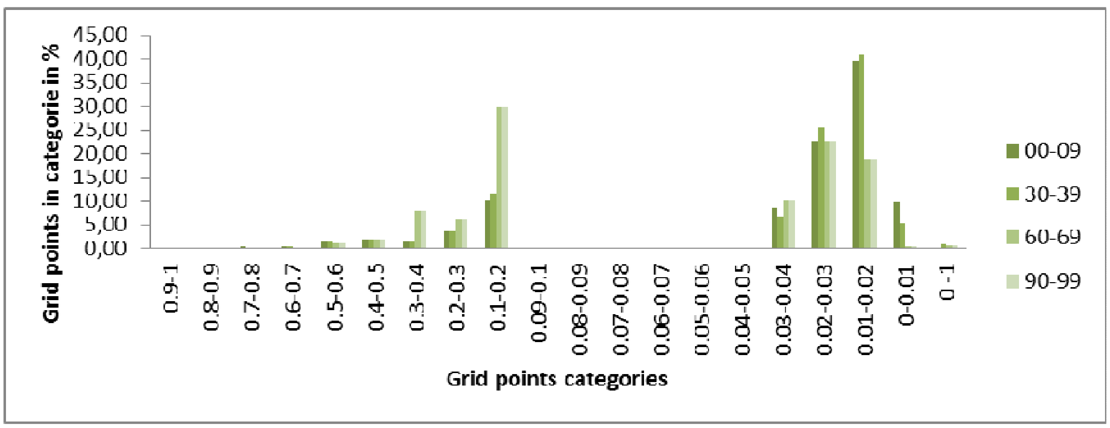

Figure 47: Comparison of grid points in different brown bear density classes based on scenario A1B

Figures 46 and 47 demonstrate increase and decrease of grid points in specific density classes under the applied climate scenarios. Class 0.1-0.2 (bears/ km²) showed the highest increase under both scenarios, class 0.01- 0.02 (bears/ km²) the strongest decrease.

3.5 Marxan

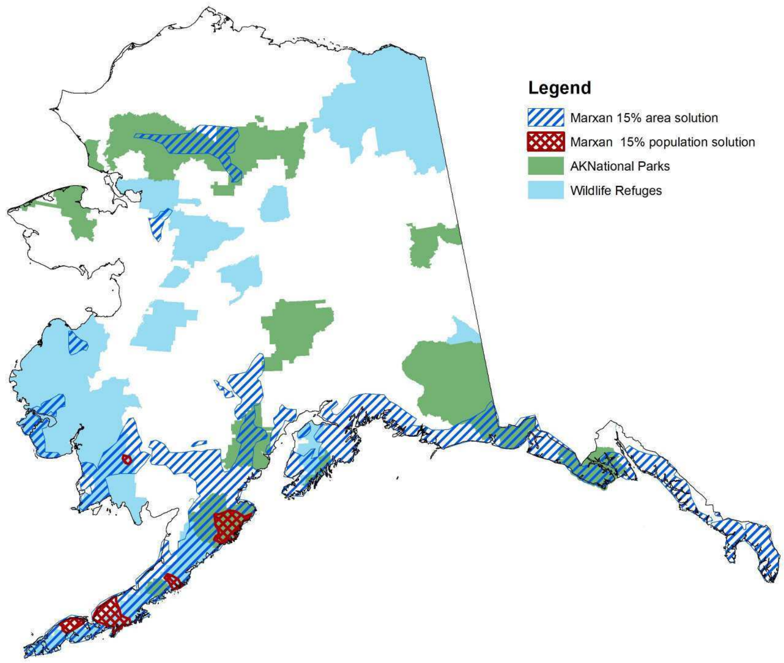

Figure 48: Potential protected areas from MARXAN covering for 2010 15% of population (red) or 15% of area (blue)

Table 10: Already protected parts of the potential protected area for the two Marxan solutions 15% coverage of suitable bear area and 15% coverage of population (in percent)

	in National Parks %	in WildlifeRefuges %	Total %
Marxan Area Solution	25.30	21.30	46.60
Marxan Population Solution	39.50	28.80	68.30

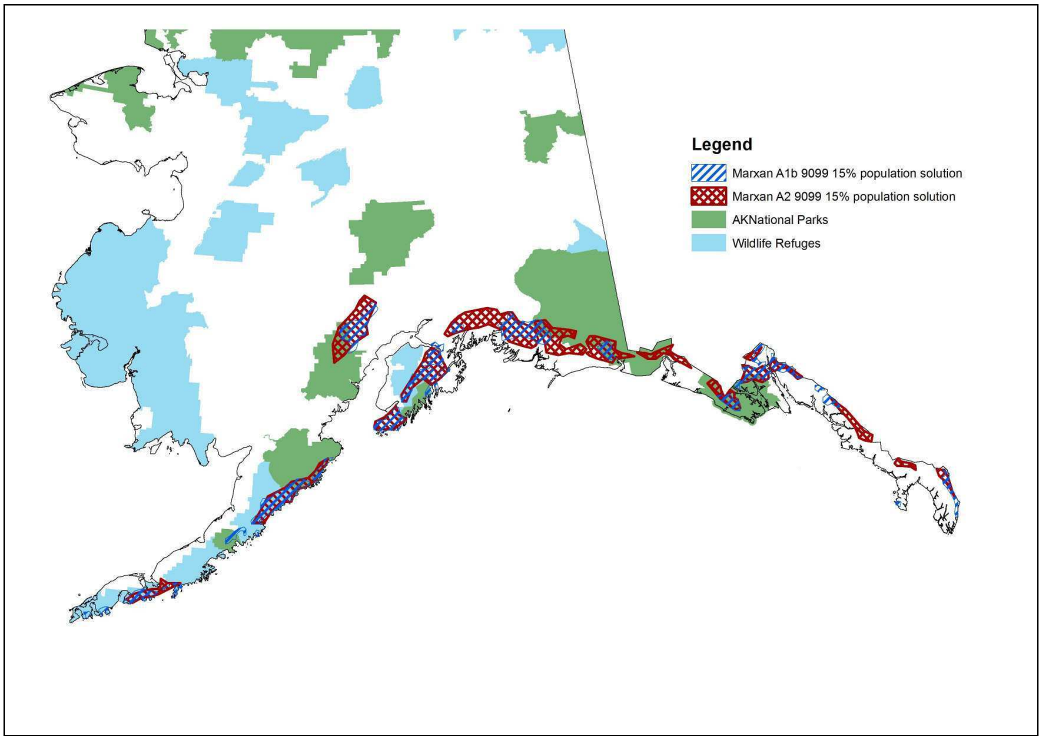

Figure 49: Potential protected areas for the decade 2090-99. Both Marxan solutions for the prediction of the A1B-scenario and the A2 scenario were overlaid.

Figure 49 shows the calculated potential protected areas for the brown bear population in the decade 2090-2099. Both areas (under scenario A1B and A2) almost cover the same regions and are overlapping in most parts. For these two Marxan applications (A1B and A2 for the decade 2090-2099) the population solution (15 % of brown bear population) was used, due to the increasing bear densities in the south.

As Table 11 demonstrates, approximately 40% of the potential protected areas are already covered by National Parks and Wildlife Refuges.

Table 11: Already protected parts of the potential protected areas for the bear population for the decade 2090-2099 based on the TreeNet model for the A1B and A2 climate scenarios (in percent)

	in National Parks %	in WildlifeRefuges %	Total %
Marxan Area of the A1B- model for the decade 2090-2099	21.90	21.20	43.10
Marxan Area of the A2- model for the decade 2090-2099	28.60	12.20	40.80

4 Discussion

When dealing with species conservation, data on size and distribution of populations is of vital importance for a good management process. Nevertheless, data accessibility is limited in many cases, e.g. due to access, political reasons, and lack of digitization or collection and data description efforts. This makes it necessary to search for alternative possibilities to estimate species abundance. In this study, the widely used density estimates published by Miller et al. (1997) were applied as a base for modeling brown bear density in terrestrial Alaska. They are over ten years old, but the best widely published publicly available data set.

4.1 Brown bear density models

Different comparisons of the model and the estimates for the Miller study areas were conducted, and the best model performed with little deviation (see Appendix 1, Table I) from the original estimates. This deviation does not necessarily signify an error, rather it could imply a better performance of TreeNet owing to the fact that Miller retrieves only one estimated number (bears per 1000 km^2) for every study area. That might be suitable, but is not truly spatially explicit and it does not correspond to the heterogeneous habitat of the study area. This heterogeneity can be better described by the TreeNet models, which are explicit in space and time and for each single pixel. Furthermore TreeNet could eventually compensate for wrong or missing data (Elith and Hastie 2008).

As demonstrated by the comparison of the modeled data and the density estimates obtained by Testa et al. (1998), the modeled data for the game management unit is very heterogeneous, leading to a high standard deviation. This should rather be the norm than the exception, and bears simply do not live all the same in plain polygons. This finding has many implications for bear and wildlife management that applies Management Zones. However, the overall and additive mean pixel values for the polygons are very similar, indicating a high accuracy of the TreeNet model. The better performance cannot be proven by any statistical method we are aware of, but only by spatial and temporal ground truthing, which is far more complicated and expensive.

The scoring of the variables decreases fast, which leads to the conclusion that the bear population could be described with a small amount of variables. Now that this fact has been confirmed, it might even be applicable for these findings to use a linear model to describe bear density, if one wishes to do so and for testing in a different statistical framework.

According to the most accurate model, ecoregions, winter temperature, and several human factors seem to have the highest influence on bear density. Landscapes relevant for bears should be stratified that way. These might have a direct effect, as in the example of the ecoregion *Aleutian meadows* which is an open habitat and which is positive for bears. Apart from the direct influence on bears, other positive effects must be considered. Some ecoregions and related temperatures ensure higher food/prey availability and result in increasing bear densities.

In some regions, like the Kenai Peninsula for instance, brown bears depend heavily on salmon as a food supply (Suring et al. 1998). The model shows that some salmon species seem to be of higher importance for the bears than others. The salmon data used in this work has some proportion of missing values. TreeNet can compensate for this, but the wide range of missing data might also have an effect on data scoring and analysis.

Human structures seem to have a strong influence on bears, thus most of the human-related variables have a negative partial dependence near human structures and up to a radius of 80 km. The change from negative to positive partial dependence is abrupt, as illustrated by the variables “distance to roads” and “distance to towns”, which indicate a threshold for the bear population. The distance of 80 km is a peculiar value, and could be related to movement and security, or impact distances that bears have for human structures.

In this context, the only exception is represented by the variable “distance to railways”, where railways seem to have a positive effect on bears. There is only one Alaskan railway which is not very frequently used and which does seemingly not involve the negative effects of roads through noise, high disturbance, and increased access for hunters. It has to be tested whether garbage or the carcasses of animals killed by train accidents (´train kill`) might attract and support the local bear population. The Alaskan railway consists of only one track going from South to North through half of the State. This “line” feature might only have a spatial effect on the model, but no actual biological explanation, considering the fact that the track passes near a Wildlife Refuge and a National Park. Specifically designed field work would help to elucidate these questions. At least, a big number of bears are affected.

4.2 Climate models

The climate models demonstrate a significant increase of bear densities in the south of Alaska and compared with the data mining density model using a higher variety of data. This result can be considered an overestimation of bear abundance, and it only predicts the ´climate envelope` of bears (potential niche) rather than the realized niche. However, it also shows that the “climatic” habitat in some regions is very suitable for bears and for their occurrence, but populations are rather suppressed by other factors like human activity or unsuitable vegetation. The trend goes the following: An increase in bear density is predicted for every decade modeled, and high densities of brown bears are expanding from the south to central Alaska. At the same time, the western coast demonstrates higher bear abundance, with the density classes 0.08- 0.2 bears per km^2 in particular predicted to increase. The results of the climate models can be interpreted to mean that the upcoming climate change has positive range increase effects on the brown bear population of Alaska and that the population density of brown bears will increase mainly in the south and along the western coast of Alaska. Moreover, northwards shifts in species distribution have been predicted by different studies (e.g., Parmesan 1996), and brown bears are among the mammals who benefit in this regard when compared, for example, to the polar bear *(Ursus maritimus)* who might be displaced accordingly (e.g., Durner et al. 2009) or mix with the brown bears. It can be assumed that with an increasing habitat for brown bears, other habitats could be displaced. However, biomes are also believed to move, and displacements might not take place as fast as predicted within the next 100 years.

The future predictions in this study are based solely on the factor “climate”, which is projected to result in a positive range expansion for the brown bears as, besides the direct positive effects of a warming climate, future impacts related to climate change should also be considered, e.g. diseases, development, human population increase, rasing consumption, and human-bear conflicts. One additional positive effect is the forecasted increase of wildfires (Stocks et al. 1998), which can perhaps be advantageous for bears because of the ensuing creation of an open landscape, enhanced berry productivity and carcasses they can feed on.

The relevance of negative indirect effects that go along with a warming climate has still to be evaluated. Land cover can be significantly altered and subsequently influence habitat suitability for brown bears, necessitating models and estimations of future landscapes similar to those conducted by Huettmann et al. (2005) and Murphy et al. (2010). Moreover, hibernation of reproducing females can be disturbed and the flooding of dens is emerging as a serious issue (Farley 2007).

Changes in food availability, fruit production of shrubs and prey abundance for instance, are not considered in the described model. Prey and other factors that influence the bear population may not be changing at the same speed as the climatic factors. Prey species and shrubs, including pollination, do not necessarily show a great resilience towards climate change, which may lead to a decrease of prey and food availability for the bears. Even though the "climate" habitat (´Climate Envelope`) spreads out over Alaska, the bear population might shrink. According to ACIA (2004), the porcupine caribou herd has already declined by 3.5% per year down to only 123,000 animals since 1989. The Western caribou herd shrank by more than 20% (113,000 animals) between 2003 and 2007, probably as the result of mid-winter warm spells. Salmon, too, is affected by changing climate and its consequences. The rising sea level can cause the flooding of lower estuaries. Streams flow more slowly in summer and display higher temperatures. With warming streams salmon become more susceptible to diseases and parasites as witnessed by stream temperatures of above 22℃ which caused massive fish kills (Haeufler et al. 2010). The protozoan parasite *Icthyophonus* had not been detected in Yukon Chinook salmon prior to 1985, but at present up to 45% of fish are infected, and result in massive population decline (Kocan et al. 2004). Declining salmon populations do not only reduce food availability for bears, but may subsequently also affect the spatial distribution of nutrient subsidies to riparian plants, which are otherwise ensured through the interspecific interaction with bears transporting salmon carcasses into forests (Helfield and Naiman 2001). It affects the entire ecosystem of which bears are part of.

When taking only the climate model into account and assuming an increase of the bear population over the next 100 years, other factors must be considered as well. An increasing number of bears might lead to intraspecific conflicts, for instance if home ranges are not changing proportionally. Not only bears, but also other predator species could increase in population size resulting in a higher competition for the same resources.

4.3 Potential protected areas

The solutions derived through Marxan indicate that the most important areas for brown bears are currently in the south of Alaska along and near the coastline. Usually that is where most people live. When Marxan is applied to the derived density model, the Alaskan Peninsula contains the most important areas. In this region the highest densities of bears can be found in combination with areas related to low human activity. In order to protect the bear population most efficiently, effective protected areas should be implemented there.

Consistent with the future climate scenarios of the decade 2090 to 2099, Marxan still designates the most important areas along the southern coast of Alaska. This part of the state holds several National Parks, and around 50 % of the proposed areas are already protected. However, all Nationalparks are virtually overruled by ANILCA state laws, reducing the federal protection levels and making them vulnerable. The use of trapping, hunting and snow mobile and ATV is such an issue, and which is counter the benefit of bears. According to the Marxan outputs, more efficient efforts should be implemented on the southern coast in order to guarantee the protection of brown bears in the future.

Brown bear behavior towards food procurement varies from the coast to the interior (Schwartz et al. 2003). Bears in the interior are not considered a distinct population, but rather occur as a different behavioral group. This rather relevant group is currently completely excluded in the Marxan solution. For further studies on protected areas, it should be of importance to include this group, since bears of the Interior might have better strategies to adapt to altered food sources caused by climate change or human influences.

4.4 Evaluation and conclusions

The climate models show a small amount of negative values. This is because TreeNet produces a scaled index of occurrence, and sometimes the units are not 1 to 1, as seen by the few negative values. Likely, the TreeNet model slightly underpredicts the densities. These data cannot be clearly mapped without calibration, but were nevertheless considered insignificant and were thus ignored during further modeling. The legend shows them as the category negative value until 0.

The results of the ground truthing were not fully comparable to the density estimates determined. No bears were detected along the river transect of 265 km in length and since the modeled prediction for this area is 17 bears per 1000 km², this is a comprehendible outcome. However, the Yukon River had experienced a severe flooding just prior to the survey and most of the riverbank was inaccessible from both sides due to large ice blocks and overthrown trees. On the other hand, the ensuing accumulations of human waste along the shore could also be seen as an attractant for bears. In any case, some bear presence has been proven through the detection of tracks in two different sample plots. Although no applicable bear density estimates were obtained in this study, ground truthing remains a suitable and important method in deriving actual data for estimate comparison and evaluation. As a matter of fact, the derived prediction model is offering a huge and convenient to test hypothesis to be challenged and further improved over the years with field data. Following the work by Booms et al 2010 a design-based field work should be achieved from now on (Magness et al. 2006) for bear monitoring.

The models created and applied in this study demonstrated an overall performance which was more than acceptable and provided robust data. However, model quality can only be determined by its input, and updated bear density data would be of highest importance here. Current studies on bear densities in Alaska (Becker 2003) involve a different survey method which can be advantageous whereby aerial line transects are surveyed, applying a double-count method to estimate the probability of detection at the apex of the detection curve. This method covers larger areas that are more representative and is considered to be more accurate (H. Reynolds, pers. comm.) and less expensive than traditional CMR techniques. However, up to now no new density estimates exist that cover the whole state of Alaska. It would be of interest and a great progress for bear conservation in Alaska and beyond to apply the principles of the model derived in this study to the context of a peer-reviewed data obtained with the new method.

Predictions of current or future brown bear densities could benefit from more environmental layers being added to the model, such as direct food availability (moose, caribou), bear mortality, and kinship. A first step for the latter could be the inclusion of harvest data explicit in space and time. The same applies to variables driving the Marxan cost function, which could be improved by additional data representing negative effects on brown bear densities (e.g. hunting, recreational activities). Additionally the Marxan cost function itself could be adjusted through the application of greater data and information available, and further connectivity software could be applied accordingly. Even though Alaska is still one of the less human-influenced brown bear distribution areas, preserving connected habitats may counter such population declines caused by habitat losses as experienced in other states and countries and could consequently ensure the protection of more wildlife and habitat under the bears´ position of “umbrella” species.

The predictions of the future climate model should not disguise additional environmental changes which could have different and rather negative effects on brown bears. Increasing transportation infrastructure, resource extraction, nitrogen input, as well as disturbance through recreational activities are considered to have a negative influence on brown bear populations. Modeling and predicting human development and impacts could be a first step in this direction. Acting proactively in research and in management could avoid additional economical and biological costs for brown bear protection.

5 References

Alaska Department of Fish and Game. 2003. Alaska Wildlife Harvest Summary 2001-2002. *Division of Wildlife Conservation Technical Publication*, Juneau, Alaska. 7pp.

Alaska Department of Fish and Game. 2006. Our Wealth Maintained: A Strategy for Conserving Alaska's Diverse Wildlife and Fish Resources. Juneau, Alaska. Xviii+ 824 pp.

Alaska Department of Fish and Game. 2007. Alaska Wildlife Harvest Summary 2006-2007, available online at http://www.docstoc.com/docs/7003693/Harvest-Summary

Alaska Department of Fish and Game. 2010a. Kenai Peninsula Brown Bear: Endangered Species in Alaska - Alaska Department of Fish and Game, available online at http://www.adfg.state.ak.us/special/esa/bear_brown/kenai_brownbear.php

Alaska Department of Fish and Game. 2010b License statistics, available online at http://www.adfg.alaska.gov/index.cfm?adfg=licensevendors.statistics

Alaska Department of Fish and Game. 2011. Salmon species of Alaska, available online at http://www.sf.adfg.state.ak.us/Static/Statewide/regulations/PDFs/salmonid.pdf

Alaska Department of Natural Resources, Land Records Information Section. 1995. Airways Alaska.

Alaska Department of Natural Resources. 2006. Alaska Coastal Management Plan, available online at http://dnr.alaska.gov/coastal/acmp/Explore/Tourintro.html

Alaska Department of Natural Resources. 2010. General water facts, available online at http://dnr.alaska.gov/mlw/water/hydro/index.htm#anchor519642

Alaska Division of Forestry. 2006. Alaska´s forests in the 21st century. 14pp.

Alaska Division of Forestry. 2010. Statewide assessment of forest resources, available online at http://forestry.alaska.gov/pdfs/2010AlaskaStatewideAssessment.pdf

Alaska Geobotany Centre. 2009. Lakes of Alaska. available online at http://data.arcticatlas.org/geodata/ak/

Araujo, M.B., Whittaker, R.J., Ladle, R.J., and M. Erhard. 2005b. Reducing uncertainty in projections of extinction risk from climate change. *Global Ecology and Biogeography*. 14: 529–538.

Archibald, W.R., Ellis, R. and A.N. Hamilton. 1987. Responses of Grizzly Bears to logging truck traffic in the Kimsquit River Valley, B.C. *Int. Conf. Bear Res. and Manage,* 7,:251–257.

Arctic Climate Impact Assessment- ACIA. 2004. Report, available online at http://www.acia.uaf.edu/pages/scientific.html

Arctic Climate Impact Assessment- ACIA. 2005. Arctic Climate Impact Assessment. Cambridge University Press, 1042p

Arendt, A., Walsh J., and W. Harrison. 2009. Changes of Glaciers and Climate in Northwestern North America during the Late Twentieth Century. *Journal of Climate*, 22: 4117–4134.

Austin, M.P. 2002. Spatial prediction of species distribution: an interface between ecological theory and statistical modelling. *Ecological Modelling*, 157: 1001–1118.

Baker, J., Goldingay, R. L., and R.J. Whelan R. J.1998. Powerline easements through forests: a case study of impacts on avifauna. Pacific Conservation Biology, 4: 79-89.

Bailey, R.G. 1983. Delineation of ecosystem regions. Environmental Management 7: 365-373.

Ball, I.R. and H.P. Possingham. 2000. Marxan version 1.8. available online at http://www.ecology.uq.edu.au/marxan.htm#1

Ballard, W.B., Spraker, T.H. and K.P.Taylor.1981. Causes of neonatal moose calf mortality and south-central Alaska. *Journal Wildlife Management*, 45: 335–342.

Ballard, W.B., Miller, S.D. and T.H. Spraker. 1982. Home range, daily movements, and reproductive biology of the brown bear in southcentral Alaska. *The Canadian Filed-Naturalist,* 96 : 1–5.

Banci, V. 1991. The status of the grizzly bear in Canada in 1990 (Status Report). Committee on the Status of Endangered Wildlife in Canada.

Baur A. and B. Baur. 1990. Are roads barriers to dispersal in the land snail *Arianta arbustorum*? *Canadian Journal of Zoology.* 68: 613–617.

Becker, E. 2003. Brown bear line transect development. Alaska *Department of Fish and Game Final Research Report.* available online at http://www.adfg.alaska.gov/static/home/library/pdfs/wildlife/research_pdfs/brb-trans03f.pdf

Ben-David, M., Titus, K. and L.R. Beier. 2004. Consumption of salmon by Alaskan brown bears: a trade-off between nutritional requirements and the risk of infanticide? *Oecologia,* 138(3): 465–474.

Benn, B. and S. Herrero. 2002. Grizzly bear mortality and human access in Ban and Yoho National Parks, 1971–1998. *Ursus*, 13: 213–221.

Bennett, A.F. 1991. Roads, roadsides and wildlife conservation: A review. Nature conservation: The role of corridors 2: 99-118.

Berger, J. 2007. Carnivore repatriation and holarctic prey: narrowing the deficit in ecological effectiveness. *Conservation Biology.* 21(4): 1105–1116.

Beyer, H. L. 2004. Hawth's Analysis Tools for ArcGIS. available online at http://www.spatialecology.com/htools.

Bhatt, U.S., et al. 2010: Circumpolar Arctic Tundra Vegetation Change Is Linked to Sea Ice Decline. *Earth Interactive*, 14: 1–20.

Blanchard, B. M., and R.R. Knight. 1990. Reactions of grizzly bears, Ursus arctos horribilis, to wildfire in Yellowstone National Park, Wyoming. *Canadian Field-Naturalist,* 104(4): 592–594.

Blanchard, B. M., and R. R. Knight. 1991. Movements of Yellowstone grizzly bears, 1975-87. *Biological Conservation,* 58: 41–67.

Boertje, R. D., W. C. Gasaway, D. V. Grangaard, D. G. Kelleyhouse, and R. O. Stephenson. 1987. Factors limiting moose population growth in Subunit 20E (Federal Aid in Wildlife Restoration Progress Report Project W-22-5, Job 1.37R). Alaska Department of Fish and Game, Juneau.

Breiman, L., Friedman, J., Olshen, R. and C. Stone.1984. Classification and Regression Trees. *Wadsworth & Brooks*, Pacific Grove, CA, 368pp.

Brown, G. 1993. The great bear almanac. *Lyons & Burford*, Publishers, New York, USA, pp. 10-13; pp. 90-171.

Bryant, M. D. 2009. Global climate change and potential effects on Pacific salmonids in freshwater ecosystems of southeast Alaska. *Climatic Change,* 95: 169–193.

Buckland, S.T., Summers, R.W. Borchers, D.L., and L. Thomas. 2006. Point transect sampling with traps or lures. *Journal of Applied Ecology*, 43(2): 377-384.

Bunnell, F., and D. Tait. 1981. Population dynamics of bears—implications. In: T.D. Smith and C. Fowler, (eds). Dynamics of large mammal populations. *John Wiley and Sons*, New York, New York, USA. pp. 75–98.

Bunnell, F. L., and T. Hamilton. 1983. Forage digestibility and fitness in grizzly bears. *International Conference on Bear Research and Management*, 5: 179–185.

Bunnell, F.L. and R.K. McCann. 1993. The Brown or Grizzly Bear. In: Bears majestic creatures of the wild. *Rodale Press*. Emmaus, Penn. 240 pp.

Byerly, M., B. Brooks, et al. 1999. Alaska commercial salmon catches, 1878-1997. Juneau, AK, *Alaska Department of Fish and Game*: 66pp.

Caughley, G. 1977. Analysis of vertebrate populations. *John Wiley & Sons*, New York, N.Y. 234pp.

Channell, R., and M.V. Lomolino. 2000a. Dynamic biogeography and conservation of endangered species. *Nature,* 403: 84–86.

Channell, R., and M.V. Lomolino. 2000b. Trajectories to extinction: Spatial dynamics of the contraction of geographical ranges. *Journal of Biogeography,* 27: 169–179.

Chapman, W. L., and J. E. Walsh. 2007. A Synthesis of Antarctic Temperatures. *J. Climate*, 20: 4096–4117.

Chapman, W., J. Walsh, M. Geist, and P. Larsen. 2008: Visual representation of statistically downscaled composite of five general circulation models. Prepared by the University of Illinois Urbana-Champaign, University of Alaska Fairbanks, and The Nature Conservancy in Alaska 2008. (IPCC AR 4 Emissions Scenario A1B; Five GCM composite; Average of 1961-1990 is baseline)

Chapin, F. S. 2006. Alaska's changing boreal forest. *Oxford University Press*, New York, 39-57.

Chernetsov, N. and F. Huettmann. 2005. Linking Global Climate Grid Surfaces with Local Long-Term Migration Monitoring Data: Spatial Computations for the Pied Flycatcher to Assess Climate-Related Population Dynamics on a Continental Scale. *LNCS* 3482, pp. 133 – 142

Chestin, I. 1996. Der Braunbär. *Neue Brehm-Bücherei*. Bd 633. Westarp, Magdeburg. 184pp.

Christensen, J.R., M. MacDuffee, R.W. MacDonald, M. Whiticar, and P.S. Ross. 2005. Persistent Organic Pollutant exposure in B.C. grizzlies: the consequence of divergent diets. *Environmental Science and Technology*. 39: 6952–6960.

Christensen, J.R., M. MacDuffee, M.B Yunker, and P.S. Ross. 2007. Hibernation associated changes in persistent organic pollutants (POP) levels and patterns in British Columbia grizzly bears. *Environmental Science and Technology*. 41: 1834–1840.

Clevenger, A.P., Purroy, F.J., de Buruaga, M.S., Purdoy, F. and M. S. de Burguaga. 1987. Status of the Brown Bear in the Cantabrian Mountains, Spain. International Conference of Bear Research and Management, 7: 1-8.

Contreras, G.P., Evans, K E., 1986. Proceedings–grizzly bear habitat symposium. *General Technical Report* INT-207. Ogden, UT: U.S. Department of Agriculture, Forest Service,Intermountain Research Station. 252 pp.

CITES. 2010. Convention on International Trade in Endangered Species of Wild Fauna and Flora. Appendices, available online at http://www.cites.org/eng/app/index.shtml

Cooney, R. 2004. The Precautionary Principle in Biodiversity Conservation and Natural Resource Management: An issues paper for policy-makers, researchers and practitioners. *IUCN*, Gland, Switzerland and Cambridge, UK. 51pp.

Craighead, D. J. 1998. An integrated satellite technique to evaluate grizzly bear habitat use. *Ursus,* 10:187–201.

Craighead, F. C., Jr., and J. J. Craighead. 1972. Grizzly bear prehibernation and denning activities as determined by radiotracking. *Wildlife Monograph,* 32: 1 –35.

Craighead, J. J., and J. A. Mitchell. 1982. Grizzly bear. In*:* Chapman, J.A. and G. A. Feldhamer (eds). Wild mammals of North America*. Johns Hopkins University Press*, Baltimore. 515-56pp.

Craighead, J. J., Sumner, J.S. and J. A. Mitchell. 1995. The grizzly bears of Yellowstone: Their ecology in the Yellowstone Ecosystem, 1959-1992*. Island Press*, Washington, DC. 556pp.

Crist, P. 2011. Bureau of Land Management. Seward Peninsula. available online at http://www.blm.gov/pgdata/etc/medialib/blm/wo/Communications_Directorate/public_affairs/landscape_approach/documents1.Par.54115.File.dat/AKSeward_memo_IC_SubmittedJan19_2011.pdf

Dean, F. C. 1987. Brown bear density, Denali National Park, Alaska, and sighting efficiency adjustment. International Conference on Bear Research and Management 7:37-43.

Del Frate, G.G. 1999. Units 7 and 15 brown bear. Pages 55-65 In M. Hicks (ed). Management report of survey and inventory activities 1 July 1996-30 June 1998. Federal Aid in Wildlife Restoration Project W-24-5 and W-27-1, Study 4.0*. Alaska Departmentof Fish and Game*, Juneau, Alaska, USA.

Derocher, A.E., Lunn, N.J., and I. Stirling. 2004. Polar bears in a warming climate. *Integrative and Comparative Biology,* 44: 163–176.

Durner, G.M., Douglas, D.C., Nielson, R.M., Amstrup, S.C., *et al*. 2009. Predicting 21st-century polar bear habitat distribution from global climate models. *Ecological Monographs,* 79: 25–58.

Eggers, D.M., J.R. Irvine, M. Fukuwaka, and V.I. Karpenko. 2005. Catch trends and status of North Pacific Salmon. (NPAFC Doc. No. 723, Rev. 3) 35pp.

Elgmork K. 1978. Human impact on a brown bear population (Ursus arctos L.). *Biological Conservation*, 13 (2): 81–103.

Elish, M and K. Elish. 2009. Application of TreeNet in Predicting Object-Oriented Software available online at http://faculty.kfupm.edu.sa/ICS/elish/files/Elish-CSMR2009-Paper.pdf

Elith, J., Leathwick, J. R. and T. Hastie. 2008. A working guide to boosted regression trees. *Journal of Animal Ecology*, 77: 802–813.

Encyclopaedia Britannica. 2010. Alaska. *Encyclopædia Britannica Online*. Ultimate Edition. United Soft Media Verlag GmbH, available online at http://www.britannica.com/EBchecked/topic/12252/Alaska.

ESRI. 2009. Online Imagery & Base Maps | Topographic Maps | ArcGIS Online Map Services. available online at http://www.esri.com/software/arcgis/arcgisonline/standard-maps.html.

Farley, S. 2005. Ecological studies of the Kenai Peninsula brown bear. *Federal Aid Final Research Report*; Alaska Department of Fish and Game.

Farley, E. V., Murphy, J. M., Adkison, M. and L. Eisne. 2007. Juvenile sockeye salmon distribution, size, condition and diet during years with warm and cool spring sea temperatures along the eastern Bering Sea shelf. *Journal of Fish Biology*, 71: 1145–1158.

Findlay, C. S. and J. Bourdages. 2000. Response time of wetland biodiversity to road construction on adjacent lands. *Conservation Biology,* 14(1): 86–94.

Flannigan, M.D., and C.E. van Wagner. 1991. Climate change and wildfire in Canda. *Canadian Journal of Forest Resources,* 21: 66–72.

Fleming. M. 1997. ALASKA. A statewide vegetation map of Alaska using phenological classification of AVHRR data. Occasional Paper - Colorado University, Institute of Arctic and Alpine Research. In; Walker, D. A. (ed.), Proceedings of the Second circumpolar arctic vegetation mapping workshop and the CAVM-North America workshop 52. 25–26. http://agdc.usgs.gov/data/projects/fhm/index.html#G

Fleming, M., Chapin, F.S.W., Cramer, W., Hufford, G. and M.C. Serreze. 2000. Geographic patterns and dynamics of Alaskan climate interpolated from a sparse station record. *Global Change Biology*, 6: 49–58.

Folk, G. E., Jr., Larson, A. and M. A. Folk. 1976. Physiology of hibernating bears. *International Conference on Bear Research and Management*, 3: 373–380.

Forman, R.T. 1995. Land mosaics: the ecology of landscapes and regions. *Cambridge University Press*, Cambridge, UK, 147pp.

Forman, R.T., and L.E. Alexander. 1998. Road and their ecological effects. *Annu. Rev. Ecol. Syst.*, 29: 207–231.

Friedman, J. 1999. Greedy funtion approximation: A gradient boosting machine. Techn. Discussion, available online at http://www.salfordsystems.com/doc/GreedyFuncApproxSS.pdf

Fritz, H.W. 2004. "The Lewis and Clark Expedition". *Greenwood Publishing Group*. 59pp.

Gallant, A.L., Binnian, E.F., Omernik, J.M., and M.B. Shasby. 1995. Ecoregions of Alaska. *U.S. Geological Survey Professional Paper,* 1567, 73pp.

Gates, N. 2010. The Alaska Almanac. *Alaska Northwest Books* (33). 240pp.

Gau, R. J. 1998. Food habitats, body condition, and habitat of the barrenground grizzly bear. *M.S. Thesis*, University of Saskatchewan, Saskatoon, Canada.

Gibeau, M.L. and S. Herrero. 1998. Roads, rails, and Grizzly Bears in the Bow River Valley, Alberta. In: G.L. Evink (ed.). Proc. Int. Conf. Ecology and Transportation. Florida Dep. Transportation, Tallahassee, Fla., 104–108.

Gibeau, M.L. and K. Heuer. 1996. Effects of transportation corridors on large carnivores in the Bow River Valley, Alberta. In; G.L. Evink, P. Garrett, D. Zeigler and J. Berry (eds.) Trends in Addressing Transportation Related Wildlife Mortality. *Proceedings of the transportation related wildlife mortality seminar*. State of Florida Department of Transportation, Tallahassee, FL. FL-ER-58-96. 13 pp.

Goldsmith, S. 2008. Structural Analysis of the Alaska Economy: What are the Drivers? *Institute of Social and Economic Research*, University of Alaska Anchorage. 140 pp.

Graeber, R. 2006. Towards a Biodiversity Assessment of the Pacific Rim: Brown bear Distribution in the Pacific Rim (Alaska, Canada, Japan and Russian Far East) in Estuaries Using Compiled Coastal Data. *Diploma thesis*. University of Alaska, Fairbanks, USA.

Green, G.I., Mattson D.J., and Peek J.M. 1997. Spring Feeding on Ungulate Carcasses by Grizzly Bears in Yellowstone National Park. *Journal of Wildlife Management,* 6: 1040-55.

Guisan, A., and Theurillat J.P. 2000. Equilibrium Modeling of Alpine Plant Distribution and Climate Change: How Far Can We Go? *Phytocoenologia*, 30: 3-4, 353-384

Guisan, A. and Zimmerman N.E. 2000. Predictive Habitat Distribution Models in Ecology. *Ecological Modeling*, 135: 147–186.

Gunther, K. A., and Renkin R. A. 1990. Grizzly Bear Predation on Elk Calves and Other Fauna of Yellowstone National Park. International Conference on Bear Research and Management, 8: 329-34.

Gyug, L., Hamilton, T., and Austin M. 2004. Grizzly Bear. *Accounts and Measures for Managing Identified Wildlife – Accounts V*. 2004. available online at http://www.env.gov.bc.ca/wld/frpa/iwms/documents/Mammals/m_grizzlybear.pdf

Haddad N.M., Browne D.R., Cunningham A., Danielson B.J., Levey D.J., Sargent S., and T. Spira. 2003. Corridor Use by Diverse Taxa. *Ecology,* 84: 609–615.

Halbrook, J.M., Morgan, T.A., Brandt, J.P., Keegan, C.E., III; Dillon, T., and T.M Barrett. 2009. *Alaska's Timber Harvest and Forest Products Industry*, 2005. *Gen. Tech. Rep*. PNW-GTR-787. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 30p.

Hamer, D., and S. Herrero. 1991. Elk, Cervus elaphus, Calves as Food for Grizzly Bears, Ursus arctos, in Banff National Park, Alberta. *The Canadian Field-Naturalist,* 105: 101-3.

Haufler, J.B., Mehl, C.A., and S. Yeats. 2010. Climate change: anticipated effects on ecosystem services and potential actions by the Alaska Region, U.S. Forest Service. Ecosystem Management Research Institute, Seeley Lake, Montana, USA.

Hayward, T.L. 1997. Pacific Ocean Climate Change: Atmospheric Forcing, Ocean Circulation and Ecosystem Response. *TREE,* 12: 150-154.

Helfield, J.M., and R.J. Naiman. 2001. Effects of Salmon-Derived Nitrogen on Riparian Forest Growth and Implications for Stream Productivity. *Ecology*, 82(9): 2403–2409

Helfield, J.M., and R.J. Naiman. 2006. Keystone Interactions: Salmon and Bear in Riparian Forests of Alaska Ecosystems*,* Volume 9, No. 2: 167-180.

Hellgren, E.C. 1998. Physiology of Hibernation in Bears. *Ursus,* 10: 467-77.

Herrero, S. 1985. Bear Attacks: Their Causes and Avoidance. Lyons and Burford, New York.

Hilderbrand, G.V., Farley, S.D., Robbins, C.T., Hanley, T.A., Titus, K., and C. Servheen. 1996. Use of Stable Isotopes to Determine Diets of Living and Extinct Bears*. Canadian Journal of Zool*ogy, 74: 2080-2088.

Hilderbrand, G.V., Schwartz, C.C., Robbins, C.T., Jacoby, M.E., Hanley, T.A., Arthur, S.M. and Servheen C. 1999a. The Importance of Meat, Particularly Salmon, to Body Size, Population Productivity, and Conservation of North American Brown Bears*. Canadian Journal of Zoology,* 77: 132-38.

Hinzman, L.D., Bettez, N.D., Bolton, W.R., Chapin, F.S. et al. 2005. Evidence and implications of recent climate change in Northern Alaska and other Arctic regions. *Climatic Change*. 72: 251-298.

Horn, H.L., Arcese, P., Brunt, K., Burger, A.E., Davis, H., et al. 2009. Part 1: Assessment of Co-location Outcomes and Implications for Focal Species Management under EBM. *Report 1 of the EBM Working Group Focal Species Project*. Integrated Land Management Bureau, Nanaimo, B.C.

Horn, H.L., Arcese, P., Brunt, K., Burger, A., Davis, H., et al. 2009. Part 3: Knowledge Base for Focal Species and their Habitats in Coastal B.C*. Report 3 of the EBM Working Group Focal Species Project. Integrated Land Management Bureau, Nanaimo, B.C*.

Huettmann, F. and Diamond, A.W. 2001. Seabird colony locations and environmental determination of seabird distribution: A spatially explicit seabird breeding model in the Northwest Atlantic. *Ecological Modelling 141*: 261-298

Huettmann, F., Franklin, S.E., and G.B. Stenhouse. 2005. Predictive Spatial Modelling of Landscape Change in the Foothills Model Forest*. Forestry Chronicle,* 81(4): 525-537.

International Arctic Science Committee. 2009. Introduction to Future Climate Change: Modeling and Scenarios for the Arctic. In: Encyclopedia of Earth. Eds. Cutler J. Cleveland (Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment). [First published in the Encyclopedia of Earth September 28, 2009; Last revised Date September 28, 2009; available online at http://www.eoearth.org/article/Introduction_to_Future_Climate_Change:_Modeling_and_Scenarios_for_the_Arctic

International Union for the Conservation of Nature. 2007. Guidelines for Applying the Precautionary Principle to Biodiversity Conservation and Natural Resource Management. available online at http://cmsdata.iucn.org/downloads/ln250507_ppguidelines.pdf

Jackson, S.D. 2000. Overview of Transportation Impacts on Wildlife Movement and Populations. 7-20 In Messmer, T.A. and West, B., (eds) Wildlife and Highways: Seeking Solutions to an Ecological and Socio-economic Dilemma. *The Wildlife Society*.

Jaeger, J.A.G., and L. Fahrig. 2001. Modelling the Effects of Road Network Patterns on Population Persistence: Relative Importance of Traffic Mortality and 'Fence Effect'. in Evink, G., editor. Proceedings of the 2001 International Conference on Ecology and Transportation (ICOET). 24-28 September 2001, Keystone Colorado. 298-312 available online at: http://www.icoet.net/downloads/ICOET2001ProceedingsPrintVersion.pdf

Kaczensky, P. 2000. Der Braunbär*. Infodienst Wildbiologie & Ökologie*. Zürich, Schweiz.

Kocan, R.M., Hershberger, P.K. and Winton, J. 2004 Ichthyophoniasis: An Emerging Disease of Chinook Salmon in the Yukon River. *Journal of Aquatic Animal Health*, 16: 58-72.

Laliberte, A.S., and W.J. Ripple. 2004. Range Contractions of North American Carnivores and Ungulates. *BioScience*, 54(2): 123-138.

Larsen, D.G., Gauthier, D.A., and R.L. Markel. 1989. Causes and Rate of Moose Mortality in the Southwest Yukon. *Journal of Wildlife Management,* 53: 548-57.

Last of the Wild Data Version 2. 2005 (LWP-2): Global Human Footprint Data Set (HF). Wildlife Conservation (WCS) and Center for International Earth Science Information Network (CIESIN). Last of the Wild Data Version 2, 2005 (LWP-2): Global Human Influence Index (HII). Wildlife Conservation (WCS) and Center for International Earth Science Information Network (CIESIN). LeFranc, M. N., Moss, M. B., Patnode, K. A., and Sugg, W. C., (eds). 1987. *Grizzly Bear Compendium*. Interagency Grizzly Bear Committee, Washington, DC.

Lewis, M. and W. Clark. 1804. *The Journal of the Lewis and Clark Expedition*. Edited by E.M. Gary, University of Nebraska–Lincoln, available online at http://lewisandclarkjournals.unl.edu/index.html

Linnell, J.D.C., Swenson, J.E., and Andersen, R. 2000. Conservation of Biodiversity in Scandinavian Boreal Forests: Large Carnivores as Flagships, Umbrellas, Indicators, or Keystones?. *Biodiversity and Conservation*, 9(7): 857-868.

Linell, J.D.C., Swenson, J.E., Anderson, R., and B. Barnes. 2000. How Vulnerable are Denning Beras to Disturbance?. *Wildlife Society Bulletin,* 28: 400-13.

Lovejoy, T.E. and L. Hannah. 2005. Climate Change and Biodiversity. *Yale University Press,* New Haven, CT. 440pp.

McDonnell M.D., Possingham H.P., Ball I.R., and E.A. Cousins. 2002. Mathematical Methods for Spatially Cohesive Reserve Design. *Environmental Model Assessment*, 7:107–114.

Mace, R.D., and Waller, J.S. 1997. Final Report: Grizzly Bear Ecology in the Swan Mountains, Montana. *Conservation Biology*, 12: 1005-16

Mader H.J.. 1984. Animal Habitat Isolation by Roads and Agricultural Fields. *Biological Conservation*, 29: 81-96.

Maehr, D.S. 1998. Keystones, Flagships, Umbrellas and Indicators – The Role of Charismatic Species and Ecologically Influential Species in Protecting Whole Ecosystems, available online at http://www.duke.edu/~mmv3/biocon/documents/Maehr1998.pdf

Mano, T. 2006. The status of brown bears in Japan. *Understanding Asian bears to secure their future*, pp. 111-121.

Margules, C.R., and M.P. Austin. 1994. Biological Models for Monitoring Species Decline: The Construction and Use of Data Bases. *Philos. Trans. R. Soc. Lond. B.*, 344: 69–75.

Mattson, D.J. 1990. Human Impacts on Bear Habitat Use. *International Conference on Bear Research and Management,* 8: 33-56.

Mattson, D.J., Wright, R.G., Kendall, K.C., C.J. and Martinka, C.J. 1995. Grizzly Bears. In E.T. LaRoe, G.S. Farris, C.E. Puckett, P.D. Doran, and M.J. Mac, eds. Our Living Resources: A Report to the Nation on the Distribution, Abundance, and Health of U.S. Plants, Animals, and Ecosystems. *U.S. Department of the Interior*, National Biological Service, Washington, DC, 103-5

Mattson, D.J. 1997. Use of Ungulates by Yellowstone Grizzly Bears (*Ursus arctos*). *Biological Conservation,* 81: 161-77.

McCracken, H. 1955. The Beast That Walks Like Man. Garden City, New York: *The Garden City Press.* 320pp

McLellan, B.N. 1985. Use Availability Analysis and Timber Selection by Grizzly Bears. In G. Contreras and K. Evans, comps. *Proceedings of the grizzly habitat symposium*, Missoula, Montana (U.S. Forest Service General Technical Report INT-207). U.S. Forest Service Intermountain Research Station, Ogden, UT. 163-66.

McLellan, B.N., and D.M. Shackleton. 1988. Grizzly Bears and Resource Extraction Industries: Effects of Roads on Behavior, Habitat Use and Demography. *Journal of Applied Ecology,* 25: 451-60.

McLellan, B.N., Hovey, F.W., Mace, R.D., Woods, J.G., et al. 1999. Rates and Causes of Grizzly Bear Mortality in the Interior Mountains of British Columbia, Alberta, Montana, Washington, and Idaho. *Journal of Wildlife Management,* 63: 911-20.

McLellan, B.N. 1990. Relationships between Human Industrial Activity and Grizzly Bears. *International Conference on Bear Research and Management,* 8: 57-64.

McLellan, B.N. 1994. Density-Dependent Population Regulation of Brown Bears. In M. Taylor, ed. Density-Dependent Population Regulation of Black, Brown, and Polar Bears. Monograph Series 3. *International Conference on Bear Research and Management,* 9: 15-24.

McLellan, B.N., and Hovey, F.W. 2001. Natal Dispersal of Grizzly Bears. *Canadian Journal of Zoology,* 79: 838-844.

McLellan, B.N., and Hovey, F.W. 2001. Habitats Selected by Grizzly Bears in a Multiple-Use Landscape. *Journal of Wildlife Management*, 65: 92-99.

McLellan, B.N., Servheen, C. and Huber, D. 2008. *Ursus arctos.* In: IUCN 2010. IUCN Red List of Threatened Species. Version 2010.4. available online at http://www.iucnredlist.org.

Miller, S. D. 1993. Brown bears in Alaska: A statewide management overview (Wildlife Technical Bulletin 11). Alaska Department of Fish and Game, Juneau.

Miller, S. D. 1995. Impacts of heavy hunting pressure on the density and demographics of brown bear populations in southcentral Alaska. (Federal Aid in Wildlife Restoration Progress Report W-24-3, Study 4.26). Alaska Department of Fish and Game, Juneau.

Miller, S. D., Becker, E. F., and W. B. Ballard. 1987. Black and brown bear density estimates using modified capture-recapture techniques in Alaska. International Conference on Bear Research and Management 7:23-35.

Miller, S.D., and M.A. Chihuly. 1987. Characteristics of Nonsport Brown Bear Deaths in Alaska. International Conference for Bear Research and Management, 7: 51-58.

Miller, S. D, White, G.C., Sellers, R.A., Reynolds, H.V., et al. 1997. Brown and black bear density estimation in Alaska using radiotelemetry and replicated mark-resight techniques. Wildlife Monograph 133:1-55.

Miller, S.D. and J. Schoen 1999. In Servheen et al. Bears: Status Survey and Conservation Action Plan 40- 46pp.

Mills, L.S., Soule, M.E., and Doak, D.F. 1993. The Keystone-Species Concept in Ecology and Conservation*. BioScience,* 43: 219 -224.

Moss, M.B., and M.N, Jr. LeFranc. 1987. Management Techniques and Strategies. In: LeFranc, M.N., Jr., Moss, M.B., Patnode, K.A., Sugg, W.C., III., eds. Grizzly

Bear Compendium. Washington, DC: The National Wildlife Federation, 137-156.

Munro, R.H.M., Nielsen, S.E., Price, M.H., Stenhouse, G.B., Boyce, M.S. 2006. Seasonal and Diel Patterns of Grizzly Bear Diet and Activity in West-Central Alberta. *Journal of Mammalogy*, 87: 1112–1121.

Murphy, K., Huettmann, F., Fresco, N., and J. Morton. 2010. Connecting Alaska Landscapes into the future- Results from an interagency climate modeling, land management and conservation projects, available online at http://www.snap.uaf.edu/files/SNAP-connectivity-2010-complete.pdf

Mystrud, I. 1983. Characteristics of Summer Beds of European Brown Bears in Norway. *International Conference on Bear Research and Management,* 5: 208-22.

Nagy, J.A., Russell, R.H., Pearson, A.M., Kingsley, M.C., and B.C. Goski. 1983a. Ecological Studies of the Grizzly Bear in Arctic Mountains, Northern Yukon Territories, 1972 to 1975. *Canadian Wildlife Service*, Edmonton, Alberta.

Nagy, J.A., Russell, R.H., Pearson, A.M., Kingsley, M.C., and C.B. Larsen. 1983b. A Study of Grizzly Bears on the Barren Grounds of Tuktoyaktuk Peninsula and Richards Island, Northwest Territories, 1974-1978. *Canadian Wildlife Service Report*, Edmonton, Alberta.

NASA. 2008. Status of Alaska land ice. American Geophysical Union conference in San Francisco available online at www.nasa.gov

NASA. 2009. Rivers of Alaska available online at http://gcmd.nasa.gov/records/GCMD_Alaska_Rivers_GIS.html

National Climatic Data Centre. 2000. Mean annual temperature and mean annual rainfall of Alaska, available online at http://coolweather.net/staterainfall/alaska.htm

National Oceanic and Atmospheric Administration Document 60, Climate of Alaska. updated by National Weather Service. avilable online at http://sled.alaska.edu/akfaq/aksuper.html#wea

National Park Service. U.S. Department of the Interior 2011. Hunting information. Available online at http://www.nps.gov/dena/parkmgmt/hunting-information.htm

National Park Service. 2011. Federal regulations for Alaska parks. available online at http://www.nps.gov/lacl/parkmgmt/lawsandpolicies.htm

National Park Service, Alaska Support Office, Land Resources Program Center 2002. “Alaska National Park Boundaries”. available online at http://www.nps.gov/akso/gis

National Wildlife Federation. 2011. Salmon and global warming. available online at http://www.nwf.org/Global-Warming/Effects-on-Wildlife-and-Habitat/Salmon.aspx

Nelson, R. A. 1980. Protein and fat metabolism in hibernating bears. *Federal Proceedings,* 39:2955–58.

Nelson, R.A., Folk, G.E., Pfeiffer, E.W., et al. 1983. Behavior, biochemistry, and hibernation in black, grizzly and polar bears. *International Conference on Bear Research and Management,* 5: 284–290.

Nevin, O.T. and B.K. Gilbert. 2004. Isotopic assessment of habitat quality and brown bear feeding behaviour. Oral presentation, 15th International Conference on Bear Research and Management.

Nielsen, S.E., Boyce, M.S., Stenhouse, G.B., and R.H.M. Munro. 2002. Modeling grizzly bear habitats in the Yellowhead Ecosystem of Alberta: Taking autocorrelation seriously. *Ursus,* 13: 45–56.

Nielsen, S.E., Boyce, M.S. and G.B. Stenhouse. 2004a. Grizzly bears and forestry. I. Selection of clearcuts by grizzly bears in westcentral Alberta, Canada. *Forest Ecology and Management,* 199: 51–65.

Nielsen, S.E., Boyce, M.S., and G.B. Stenhouse. 2006. A habitat-based framework for grizzly bear conservation in Alberta. Biological Conservation 130: 217–229.

Nielsen, S.E., Cranston, J. and G.B. Stenhouse. 2009. Identification of Priority Areas for Grizzly Bear Conservation and Recovery in Alberta, Canada, Journal of Conservation Planning, 5: 38–60.

Nielsen, S.E., Herrero, S., Boyce, M.S., Mace, R.D., Benn, B., Gibeau, M.L. and S. Jevons. 2004c. Modelling the spatial distribution of human-caused grizzly bear mortalities in the Central Rockies Ecosystem of Canada. Biological Conservation, 120: 101–113.

Nielsen, S.E., Munro, R.H.M., Bainbridge, E., Boyce, M.S. and G.B. Stenhouse. 2004b. Grizzly bears and forestry. II. Distribution of grizzly bear foods in clearcuts of west-central Alberta. *Forest Ecology and Management*, 199: 67–82.

Nielsen, S.E., Stenhouse, G.B., Beyer, H.L., Huettmann, F., Boyce, M.S. 2008. Can natural disturbance-based forestry rescue a declining population of grizzly bears? Biological Conservation, 141: 2193-2207.

Noss, R. F., Quigley, H.B., Hornocker, M.G., Merrill, T. and P.C. Paquet. 1996. Conservation Biology and Carnivore Conservation in the Rocky Mountains. *Conservation Biology,* 10(4): 949–963.

Noss, R. F., O'Connell, M.A. and D. D. Murphy. 1997. The science of conservation planning: habitat conservation under the Endangered Species Act. *Island Press*, Washington, D.C., USA. 236pp.

Nowacki, G.; Spencer, P.; Fleming, M.; Brock, T.; and T. Jorgenson. 2001. Ecoregions of Alaska: 2001. *U.S. Geological Survey Open-File Report*, 02–297 (map).

Nowak, R.M. 1999. Walker's mammals of the world. The Johns Hopkins University Press; 6th edition, 2015pp.

Olsen, T., Gilbert, B.K., and R.C. Squibb. 1997. The effects of increasing human activity on brown bear use of an Alaskan river. *Biological Conservation*, 82(1): 95–99.

Omernik, J.M. 1987. Ecoregions of the Conterminous United States. *Annals of the Association of American Geographers*, 77(1): 118–125.

Omernik, J. M, and R. G Bailey. 1997. Distinguishing between watersheds and ecoregions 1. *Journal of the American Water Resources Association,* 33(5): 935–949.

Oppenheimer, M. 1989. Climate change and environmental pollution: Physical and biological interactions. *Climate Change,* 15: 225–270.

Paetkau D.H, Shields G.F, and C. Strobeck. 1998. Gene flow between insular, coastal, and interior populations of brown bears in Alaska. *Mol. Ecol*,. 1998a, 7: 1283–1292.

Parmesan, C. 1996. Climate and species range. *Nature,* 382: 765–766.

Partridge, S., Smith, T., and T. Lewis. 2009. Black and brown bear activity at selected coastal sites in Glacier Bay National Park and Preserve, Alaska: A preliminary assessment using noninvasive procedures: *U.S. Geological Survey Open-File Report,* 1169, 62 pp.

Pasitschniak-Arts, M. 1993. Mammalian species: Ursus arctos*. American Society of Mammalogy,* 439: 1–10.

Patterson, B. D., Ceballos, G., Sechrest, W., Tognelli, M.F., Brooks, T., Luna, L., Ortega, P., Salazar, I. and B. E. Young. 2007. Digital Distribution Maps of the Mammals of the Western Hemisphere, version 3.0. *NatureServe*, Arlington, Virginia, USA. available at www.natureserve.org; www.natureserve.org/infonatura

Picton, H.D., Mattson, D.M., Blanchard, B.M. and R.R. Knight. 1985. Climate, carrying capacity and the Yellowstone Grizzly Bear. In Contreras, G.P. and K.E. Evans (eds). Proc. Grizzly Bear Habitat Symp.. U.S. Dep. Agric. For. Serv., Intermtn. Res. Stn., Ogden, Utah, *Gen. Tech. Rep*. INT-207, 129–135.

Possingham, H. P., Ball, I.R. and S. Andelman. 2000. Mathematical methods for identifying representative reserve networks. In: Ferson, S. and M. Burgman (eds) Quantitative methods for conservation biology. *Springer-Verlag*, New York, 291–305.

Proctor, M.F., McLellan, B.N., Strobeck, C., and R. M.R Barclay. 2004. Gender-specific dispersal distances of grizzly bears estimated by genetic analysis. Canadian Journal of Zoology, 82(7): 1108–1118.

Proctor, M. F., McLellan B. N., Strobeck, C. and R.M.R. Barclay. 2005. Genetic analysis reveals demographic fragmentation of grizzly bears yielding vulnerably small populations. *Proceedings of the Royal Society of London B Biological Sciences,* 272: 2409–2416.

Proctor, M. F., Servheen, C., Miller, S. D., Kasworm, W. F. and W.L. Wakkinen. 2004. A comparative analysis of management options for grizzly bear conservation in the US-Canada trans-border area. *Ursus,* 15:145–160.

Reijnen, R., Foppen, R., and G. Veenbaas. 1997. Disturbance by traffic of breeding birds: Evaluation of the effect and considerations in planning and managing road corridors. *Biodiversity and Conservation*. 6(4): 567-581.

Reynolds, H. V. 1976. North slope grizzly bear studies (Federal Aid in Wildlife Restoration, Final Report Project W-17-6 and W-17-7, Jobs 4.8R, 4.9R, 4.10R, and 4.11R). Alaska Department of Fish and Game, Juneau.

Reynolds, H.V., Curatolo, J.A., and R. Quimby.1997. Denning ecology of grizzly bears in northeastern Alaska. *International Conference on Bear Research and Management,* 3: 403–409.

Reynolds, H. V., and G. Garner. 1987. Patterns of grizzly bear predation on caribou in northern Alaska. International Conference on Bear Research and Management 7:59-67.

Richardson J. H., Shore R. F. and J-R. Treweek. 1997. Are major roads a barrier to small mammals? *Journal of Zoology,* 243: 840–846.

Richardson, K. 2009. Synthesis Report. In *Climate Change: Global Risks, Challenges & Decisions. Summary of the Copenhagen Climate Change Congress*. pp. 10–12.

Roberge, J.-M. and P. Angelstam. 2004. Usefulness of the Umbrella Species Concept as a Conservation Tool. *Conservation Biology*, 18(1): 76–85.

Rode, K.D., Farley, S.D., Fortin, J. and C.T. Robbins. 2006. Nutritional consequences of experimentally introduced tourism in brown bears*. Journal of Wildlife Management*, 71(3): 929–939.

Rode, K.D., Farley, S.D., and C.T. Robbins. 2008. Sexual dimorphism, reproductive strategy, and human activities determine resource use by brown bears. *Ecology,* 87(10): 2636–2646.

Rodríguez, J.P. 2002. Range contraction in declining North American bird populations. *Ecological Applications,* 12: 238–248.

Quang, P.X., and E.F. Becker. 1996. Line transect sampling under varying conditions with application to aerial surveys. *Ecology*, 77: 1297–1302.

Salford Systems. 2003. Software TreeNet. San Diego, CA. available online at http://www.salford-systems.com/.

Salford Systems.

Sanderson, E.W., Jaiteh, M., Levy, M.A., Redford, K.H., Wannebo, A.V., and G. Woolmer. 2002. The Human Footprint and The Last of the Wild. *BioScience,* 52(10): 91–904.

Scenarios Network for Alaska Planning (SNAP). 2008. Preliminary report to the Governor's subcabinet on climate change. SNRAS Pub. No. MP 2008-06, University of Alaska, Fairbanks.

Scenarios Network for Alaska Planning (SNAP). 2010. Climate datasets for Alaska. available online at http://www.snap.uaf.edu/downloads/alaska-climate-datasets

Schoen, J.W. 1990. Bear habitat management: a review and future perspective. *International Conference on Bear Research and Management*, 8: 143–154.

Schoen, J.W. 1991. Forest management and bear conservation. In: N. Maruyama, N. Bobek, B., Ono, Y., Regelin, W. Bartos, L. and P. Ratcliffe (eds.) Proc. of the International Symposiumo n Wildlife Conservation. V Int. Congress of Ecology. Tsukuba and Yokohama, Japan. 97-101.

Schoen, J. W., Flynn, R. W., Suring, L. H., Titus, K. and L R. Beier. 1994. Habitat-capability model for brown bear in southeast Alaska. *International Conference on Bear Research and Management,* 9(1): 327–337.

Schoen, J. W., and S. D. Miller. 2002. New strategies for bear conservation: Collaboration between Resource Agencies and Environmental Organizations. Ursus 13:361-67.

Schwartz, C.C., Arthur, S.M., G. Del Frate.1999. Cumulative effects model verification, sustained yield estimation, and population viability management of the Kenai Peninsula, Alaska, brown bear. Federal Aid in Wildlife Restoration Report. *Alaska Department of Fish and Game*, Juneau, Alaska, USA. 27 pp.

SEDAC. 2010.SEDAC-Last of the Wild: Methods. available online at http://sedac.ciesin.columbia.edu/wildareas/methods.jsp

Selkowitz, D. 2009. A Novel Approach to Mapping Vegetation Cover in Alaska Using the Multi-angular Imaging SpectroRadiometer (MISR). American Geophysical Union, Fall Meeting 2009, abstract #GC51A-0713

Simberloff, D. 1998. Flagships, umbrellas, and keystones: Is single-species management passé in the landscape era? *Biological Conservation*, 83(3): 247-257.

Snyder, S. A. 1991. Ursus arctos horribilis. In: Fire Effects Information System, [Online]. *U.S. Department of Agriculture*, Forest Service, Rocky Mountain Research Station, Fire Sciences. available online at http://www.fs.fed.us/database/feis/

Stafford, J.M., G. Wendler, and J. Curtis. 2000. Temperature and precipitation of Alaska: 50 year trend analysis. Theor. Appl. Climatol. Vol. 67: 33-44.

State of the Salmon Project, Wild Salmon Center and Ecotrust. Dr. Xan Augerot. 2002. available online at www.stateofthesalomon.org

Stocks, B.J., Fosberg, M.A., Lynham, T.J., Mearns, L., et al. 1998. Climate change and forest fire potential in Russian and Canadian boreal forests. *Climatic Change*, 38(1): 1–13.

Storer, T. I. and Tevis, L. P. 1955. California Grizzly. *University of California Press*, Berkeley, California. 335pp.

Stringham, S.F. 1990.Grizzly bear reproductive rate relative to body size. *International Conference on Bear Research and Management*, 8: 433–443.

Sturm, M., Holmgren, J., McFadden, J.P. , Liston, G.E., Chapin, F.S. , and C. H. Racine. 2001. Snow–Shrub Interactions in Arctic Tundra: A Hypothesis with Climatic Implications. *J. Climate*, 14: 336–344.

Suring, L.H., Barber, K.R, Schartz, C.C., Bailey, T.N., Shuster, W.C. and M.D. Tetreau. 1998. Analysis of cumulative effects on brown bears on the Kenai Peninsula, Southcentral Alaska. *Ursus,* 10: 107–117.

Suring LH, and G.DelFrate .2002. Spatial analysis of locations of brown bears killed in defense of life or property on the Kenai Peninsula, Alaska, USA. *Ursus*, 13: 237–245.

Sutherland, W.J. 1996. Ecological census techniques: a handbook. *Cambridge University Press*. UK. 448pp.

Tape, K., M. Sturm, and C. Racine. 2006. The evidence for shrub expansion in Northern Alaska and the Pan-Arctic. *Global Change Biology*, 12: 686–702.

Taylor, S. 2008. Climate warming causes phenological shift in Pink Salmon, Oncorhynchus gorbuscha, behavior at Auke Creek, Alaska. *Global Change Biology,* 14: 229–235.

Testa, J. W., Taylor, W.P. and S. D. Miller. 1998. Impacts of increased hunting pressure on the density and dynamics of brown bear populations in southcentral Alaska (Federal Aid in Wildlife Restoration Progress Report, W-27-1, Study 4.28). *Alaska Department of Fish and Game*, Juneau.

Tucker, C.J. 1979. Red and Photographic Infrared Linear Combinations for Monitoring Vegetation. *Remote Sensing of Environment*, 8(2): 127–150.

U.S. Census Bureau. 2009. Alaska 2008 Population Estimates.

U.S. Department of the Interior. 1964. Natural Resources of Alaska.

U.S. Department of the Interior. 2006. Fiscal year 2006 report. available online at http://www.doi.gov/budget/2006/06Hilites/toc.html

U.S. Fish and Wildlife Service 2001. Information Technology Management, Branch of Data and Systems Services, Region 9. available online at http://www.fws.gov/data/datafws.html

U.S. Geological Survey 2007. How Does Climate Change Influence Alaska's Vegetation?
Insights from the Fossil Record. available online at http://pubs.usgs.gov/fs/fs-0071-97/

U.S. Geological Survey 2009. The National Map Seamless Server. DEM of Alaska. available online at http://agdcftp1.wr.usgs.gov/pub/projects/dem/300m/akdem300m.tar.gz

U.S. Geological Survey 2010. USGS - U.S. Geological Survey. available online at http://www.usgs.gov/. and http://agdc.usgs.gov/data/usgs/erosafo/ecoreg/index.html

U.S. Global Change Research Program. 2009. Global climate change impacts in the United States. *Cambridge University Press*, New York. available online at http://downloads.globalchange.gov/usimpacts/pdfs/alaska.pdf

Waits, L., Taberlet, P., Swenson, J.E., Sandegren, F., and R. Franzen. 2000. Nuclear DANN satellite analysisof genetic diversity and gene flow in the Scandinavian brown bear (Ursus arctos). *Molecular Ecology,* 9: 421–431.

Walker, D.A., Bhatt, U.S., Raynolds, M.K., Comiso,, J.E., et al. 2009. The Arctic: Land: Vegetation. State of the Climate in 2008. 104-105.

Walsh, J., Chapman, W.L., Romanovsky, V., Christensen J.H., and M. Stendel. 2008. Global climate model performance over Alaska and Greenland. Journal of Climate. v. 21 pp. 6156-6174.

Warman, L. D., Sinclair, A. R. E., Scudder, G. G. E., Klinkenberg, B. and R.L. Pressey. 2004-06. Sensitivity of systematic reserve selection to decisions about scale, biological data, and targets: Case study from Southern British Columbia. *Conservation Biology*, 18(3): 655–666.

Watts, P. D., C. Jonkel, and K. Ronald. 1981. Mammalian hibernation and the oxygen consumption of a denning black bear (*Ursus americanus*). *Comparative Biochemistry and Physiology,* 69: 121–123.

Weaver, J. L., P. C. Paquet, and L. F. Ruggiero. 1996. Resilience and conservation of large carnivores in the Rocky Mountains. Conservation Biology, 10: 964–76.

Weier ,J. and D. Herring. 2000. Measuring Vegetation (NDVI & EVI). 30. available online at http://earthobservatory.nasa.gov/Features/MeasuringVegetation/measuring_vegetation_2.php

Wiegand, Thorsten, Javier Naves, Thomas Stephan, and Alberto Fernandez. 1998. Assessin the risk of extinction for the brown bear (Ursus arctos) in the Cordillera Cantabrica, Spain. *Ecological Monographs*, 68: 539–570.

Worldwide Fund for Nature- WWF. 2009. Lessons not learned. 20 years after the Exxon Valdez oil spill. available online at http://www.worldwildlife.org/what/howwedoit/policy/WWFBinaryitem11907.pdf

Wright, S. 1977. Evolution of genetics of populations. *University of Chicago Press*, Chicago. 520pp.

Zager, P., C. Jonkel, and J. Habeck. 1983. Logging and wildfire influence on Grizzly Bear habitat in northwestern Montana*. International Conference on Bear Research and Management,* 5: 124–132.

Picture sources

Figure 6: Ursus arctos

http://www.juergen-spiess.de/gallery/v/bwa-06-04/bwa_060430_16090801_gallery.jpg.html

Declaration

Hiermit versichere ich gemäß § 9 Abs. 5 der Prüfungsordnung für den integrierten binationalen Master-Studiengang Internationaler Naturschutz (engl.: International Nature Conservation) vom 16.08.2006, dass ich die vorliegende Arbeit selbstständig verfasst und keine anderen als die angegebenen Hilfsmittel verwendet habe. Diese Arbeit wurde nicht in der gleichen oder einer ähnlichen Form bereits einem anderen Prüfungsausschuss vorgelegt und wurde bisher noch nicht veröffentlicht.

Hereby I affirm – according to § 9 section 5 of the examination regulations for the integrated bi-national Master programme International Nature Conservation (deutsch: Internationaler Naturschutz) from 16.08.2006 – that I have penned the present thesis autonomously and that I did not use any other resources than those specified above. This work was not submitted previously in same or similar form to another examination committee and was not yet published.

Göttingen, den 21.02.2011 Antje Henkel

Appendix 1: TreeNet Models

Table I: Table of applied different models compared with the actual Miller study areas. Because a direct contrast was unclear, the deviation squares to the actual Miller density were taken for each study area, summed and then rooted. To detect the deviation, the model with the minimum deviation was subtracted from all models.

ABECO61 0	ABECO2 0	All215	all61 0	all203 0	cat215	cat61 0	cat203 0	strong21 5	strong61 0	strong20 30	supe r	ABECO21 5	AB2030Au to	AB02150 01	AB6100 1	K215aut o	K2030oo 1	K1530aut o	GBDen s
13,1	13,1	17,0	13,1	13,1	17,2	13,1	13,1	17,2	13,1	13,1	13,1	17,3	13,1	17,4	13,1	15,4	13,1	13,1	7
37,4	**37,4**	**100,0**	**37,5**	**37,4**	**104,8**	**37,4**	**37,2**	**104,8**	**37,5**	**37,4**	**37,5**	**105,6**	**37,4**	**108,6**	**37,4**	**70,1**	**37,3**	**37,6**	
11,2	11,2	12,2	11,2	11,2	12,9	11,2	11,2	12,0	11,2	11,2	11,1	12,8	11,2	12,8	11,2	15,3	11,4	11,6	10,7
0,3	**0,5**	**1,5**	**0,5**	**0,5**	**2,2**	**0,5**	**0,5**	**1,3**	**0,5**	**0,5**	**0,4**	**2,1**	**0,5**	**2,1**	**0,5**	**4,6**	**0,7**	**0,9**	
24,5	24,5	24,3	24,5	24,5	24,3	24,5	24,5	24,3	24,5	24,5	24,6	24,4	24,5	24,2	24,5	23,8	24,6	24,6	14,6
98,6	**9,9**	**9,7**	**9,9**	**9,9**	**9,7**	**9,9**	**9,9**	**9,7**	**9,9**	**9,9**	**10,0**	**9,8**	**9,9**	**9,6**	**9,9**	**9,2**	**10,0**	**10,0**	
18,4	18,4	19,1	18,4	18,4	19,2	18,4	18,4	19,2	18,4	18,4	18,4	19,2	18,4	19,2	18,4	18,5	18,4	18,5	16
5,9	**2,4**	**3,1**	**2,4**	**2,4**	**3,2**	**2,4**	**2,4**	**3,2**	**2,4**	**2,4**	**2,4**	**3,2**	**2,4**	**3,2**	**2,4**	**2,5**	**2,4**	**2,5**	
17,9	17,9	18,2	17,9	17,9	17,9	17,9	17,9	18,2	17,9	17,9	17,9	18,0	17,9	18,3	17,9	14,7	17,9	17,7	17,9
0,0	**0,0**	**0,1**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,1**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,1**	**0,0**	**10,1**	**0,0**	**0,0**	
27,0	27,2	25,8	27,0	27,2	26,4	27,1	27,3	25,5	27,0	27,2	27,3	26,5	27,2	25,0	27,1	24,1	26,9	26,8	27,1
0,0	**0,0**	**1,6**	**0,0**	**0,0**	**0,5**	**0,0**	**0,0**	**2,5**	**0,0**	**0,0**	**0,0**	**0,4**	**0,0**	**4,5**	**0,0**	**9,1**	**0,0**	**0,1**	
28,4	28,4	28,2	28,4	28,5	28,2	28,4	28,4	28,2	28,4	28,4	28,4	28,2	28,4	28,2	28,4	28,4	28,4	28,4	29,1
0,5	**0,5**	**0,8**	**0,5**	**0,4**	**0,8**	**0,5**	**0,5**	**0,8**	**0,5**	**0,5**	**0,5**	**0,8**	**0,5**	**0,7**	**0,5**	**0,4**	**0,5**	**0,5**	
24,9	24,9	24,7	24,9	24,9	24,7	24,9	24,9	24,6	24,9	24,9	24,9	24,7	24,9	24,7	24,9	21,2	24,9	24,8	29,5
20,9	**20,9**	**23,1**	**20,9**	**20,9**	**23,4**	**21,0**	**21,0**	**24,1**	**20,9**	**20,9**	**20,9**	**23,1**	**20,9**	**23,4**	**20,9**	**68,2**	**21,3**	**22,1**	
27,2	27,2	27,0	27,2	27,2	26,9	27,2	27,2	27,0	27,2	27,2	27,2	26,9	27,2	26,9	27,2	25,5	27,2	27,2	34
46,6	**45,7**	**49,3**	**46,7**	**45,7**	**51,1**	**46,7**	**46,0**	**48,7**	**46,7**	**45,7**	**46,3**	**49,8**	**45,6**	**50,8**	**46,7**	**71,7**	**46,2**	**46,7**	
191,3	191,3	208,9	191, 5	191,5	204,9	191,4	191,5	202,2	191,3	191,3	191, 4	204,7	191,3	201,7	191,5	253,7	194,2	195,0	191,3

ABECO610	ABECO20	All215	all610	all2030	cat215	cat610	cat2030	strong215	strong610	strong2030	super	ABECO215	AB2030Auto	AB0215001	AB61001	K215auto	K2030oo1	K1530auto	GBDens
0,0	**0,0**	**309,7**	**0,0**	**0,1**	**184,5**	**0,0**	**0,1**	**118,0**	**0,0**	**0,0**	**0,0**	**178,9**	**0,0**	**108,1**	**0,0**	**3892,5**	**8,4**	**13,4**	
549,7	549,7	432,8	546,2	549,8	419,2	549,4	549,9	393,5	550,1	553,1	550,3	418,2	549,8	409,3	548,2	453,0	546,5	542,6	550,8
1,3	**1,3**	**13913,1**	**21,5**	**0,9**	**17325,4**	**2,0**	**0,8**	**24737,7**	**0,5**	**5,4**	**0,3**	**17593,0**	**1,0**	**20025,8**	**6,6**	**9568,7**	**18,8**	**67,0**	
17,63	9,88	1200,99	11,67	9,85	1475,46	10,03	9,88	2087,58	9,90	10,23	9,87	1497,22	9,86	1694,75	10,41	1142,26	12,15	16,74	s²
4,198	3,144	34,655	3,417	3,139	38,412	3,167	3,144	45,690	3,147	3,198	3,141	38,694	3,140	41,167	3,226	33,797	3,486	4,092	s
1,06	**0,00**	**31,52**	**0,28**	**0,00**	**35,27**	**0,03**	**0,00**	**42,55**	**0,01**	**0,06**	**0,00**	**35,55**	**0,00**	**38,03**	**0,09**	**30,66**	***0,35***	**0,95**	difMin

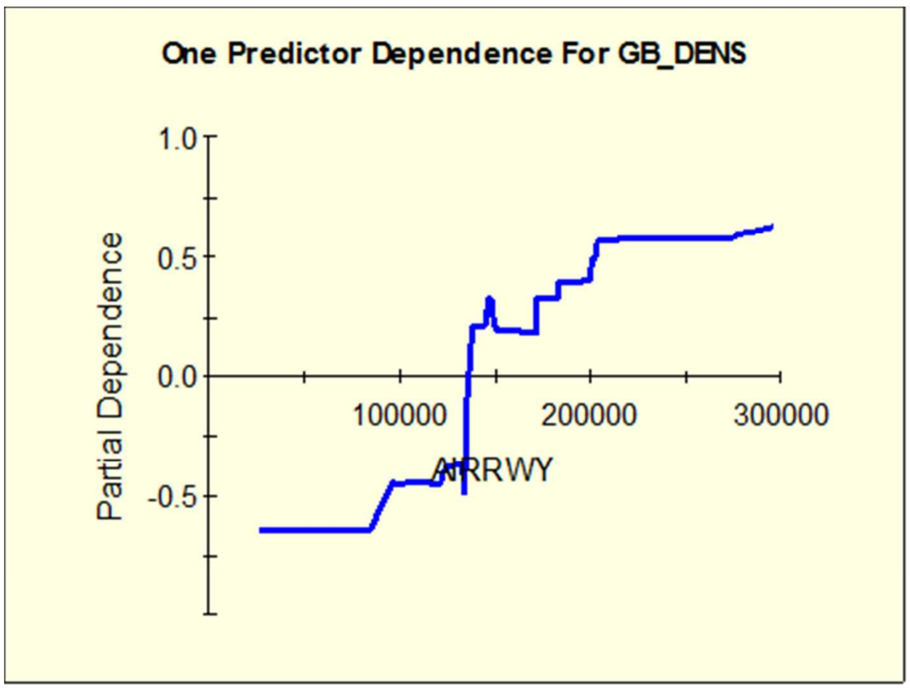

Figure I: Partcial dependence for “Distance to airways” for the All2030 1500-model

Appendix 2

Table II: Examplary TreeNet scoring of all variables. This model (All2030) was used to build the “Strong”- Model, by including all variables from T1200N until DB-Coho.

Variable	Score	
T1200N	100,00	
ECO2	72,30	
AB_PINK	57,32	
COASTDI	31,72	
ROADS	31,62	
AIRRWY	28,26	
DISTTRA	23,69	
AB_SOCK	13,67	
ECO1	13,62	
DB_CHIN	13,49	
DB_SOCK	11,25	
EUCDIST	11,23	
T600N	11,05	
LAKESDI	8,01	
AKDEM30	6,97	
DB_CHUM	4,09	
DB_COHO	3,54	
VEGCLS_	2,61	
P1200N	1,90	
HFP_N_A	1,00	
AB_COHO	0,77	
P600N	0,67	
HII_N_A	0,65	
CHINOOK	0,39	
MEANNND	0,33	
SLOPE_A	0,32	
ASPECT_	0,32	
RIV_DIST	0,27	
DB_STEE	0,16	
DB_PINK	0,12	
CHUM_PO	0,01	
FIRES60	0,01	
FIRES80	0,01	
FIRES90	0,01	
FIRES70	0,00	
FIRES50	0,00	

From the three evaluated models, the variables were taken that were most frequently high scored from TreeNet.

Table III: Example of one “Strong” Model used to build the final TreeNet Model, it was cut after DB_COHO

<table>
<tr><th>Variable</th><th>Score</th><th></th></tr>
<tr><td>ECO2</td><td>100,00</td><td>|||||||||||||||||||||||||||||||||||||||||
|</td></tr>
<tr><td>T1200N</td><td>66,43</td><td>||||||||||||||||||||||||||||</td></tr>
<tr><td>AB_PINK</td><td>48,91</td><td>||||||||||||||||||||</td></tr>
<tr><td>ROADS</td><td>30,00</td><td>||||||||||||</td></tr>
<tr><td>AIRRWY</td><td>28,77</td><td>|||||||||||</td></tr>
<tr><td>COASTDI</td><td>28,06</td><td>|||||||||||</td></tr>
<tr><td>DISTTRA</td><td>19,39</td><td>|||||||</td></tr>
<tr><td>AB_SOCK</td><td>17,75</td><td>|||||||</td></tr>
<tr><td>DB_CHIN</td><td>12,78</td><td>||||</td></tr>
<tr><td>T600N</td><td>11,68</td><td>||||</td></tr>
<tr><td>EUCDIST</td><td>11,20</td><td>||||</td></tr>
<tr><td>DB_SOCK</td><td>10,52</td><td>||||</td></tr>
<tr><td>DB_COHO</td><td>3,16</td><td></td></tr>
<tr><td>AKDEM30</td><td>1,20</td><td></td></tr>
<tr><td>ECO1</td><td>0,90</td><td></td></tr>
<tr><td>CHINOOK</td><td>0,83</td><td></td></tr>
<tr><td>AB_COHO</td><td>0,82</td><td></td></tr>
<tr><td>P600N</td><td>0,63</td><td></td></tr>
<tr><td>MEANNND</td><td>0,25</td><td></td></tr>
<tr><td>ASPECT_</td><td>0,18</td><td></td></tr>
<tr><td>SLOPE_A</td><td>0,18</td><td></td></tr>
</table>

Appendix 3: Description of the enviornmantal variables

Table IV: Human influence Index categories by Sanderson et al. (2002)

Variable category	Influence Score
Influence of Population Density/ sq. km	
0 – 0.5	0
0.6 – 1.5	1
1.6 – 2.5	2
2.6 – 3.5	3
3.6 – 4.5	4
4.6 – 5.5	5
5.6 - 6.5	6
6.6 – 7.5	7
7.6 – 8.5	8
8.6 – 9.5	9
> 9.5	10
Influence Score of Railroads	
Within 2 km of railroads	8
Beyond 2 km of railroads	0
Influence Score of Major Roads	
Within 2 km of roads	8
Within 2 to 15 km of major roads	4
Beyond 15 km of major roads	0
Influence Score of Navigable Rivers	
Within 15 km of navigable rivers	4
Beyond 15 km of navigable rivers	0
Influence Score of Coastlines	
Within 15 km of coastlines	4
Beyond 15 km of coastlines	0

Influence Score of Nighttime Stable Lights Values	
0	0
1-38	3
39 - 88	6
>=89	10
FH Line breaks like here I would fully avoid	
Urban Polygons	
Inside urban polygons	10
Outside urban polygons	0
Land Cover Categories	
Urban areas	10
Irrigated agriculture	8
Rain-fed agriculture	3
Other cover types including forests, tundra, and deserts	0

Ecoregion Mapping

Table V: Ecoregions

Level 1	Level 2	Ecoregion
1 Polar (-like)		
	Arctic Tundra	
		Beaufort Coastal Plain
		Brooks Foothills
		Brooks Range
	Bering Tundra	
		Kotzebue Sound Lowlands
		Seward Peninsula
		Bering Sea Islands
2 Boreal (-like)		
	Bering Taiga	
		Nulato Hills
		Yukon-Kuskokwim Delta
		Ahklun Mountains
		Bristol Bay Lowlands

Intermontane Boreal

- Kobuk Ridges and Valleys
- Ray Mountains
- Davidson Mountains
- Yukon-Old Crow Basin
- North Ogilvie Mountains
- Yukon-Tanana Uplands
- Tanana-Kuskokwim Lowlands
- Yukon River Lowlands
- Kuskokwim Mountains

Alaska Range Transition

- Lime Hills
- Alaska Range
- Cook Inlet Basin
- Copper River Basin

3 Maritime (-like)

Aleutian Meadows

- Alaska Peninsula
- Aleutian Islands

Coastal Rainforests

- Alexander Archipelago
- Boundary Ranges
- Chugach-St. Elias Mountains
- Gulf of Alaska Coast
- Kodiak Island

Coast Mountains Transition

- Wrangell Mountains
- Kluane Range

(Detailed information at: http://agdcftp1.wr.usgs.gov/pub/projects/fhm/akecoregions.htm)

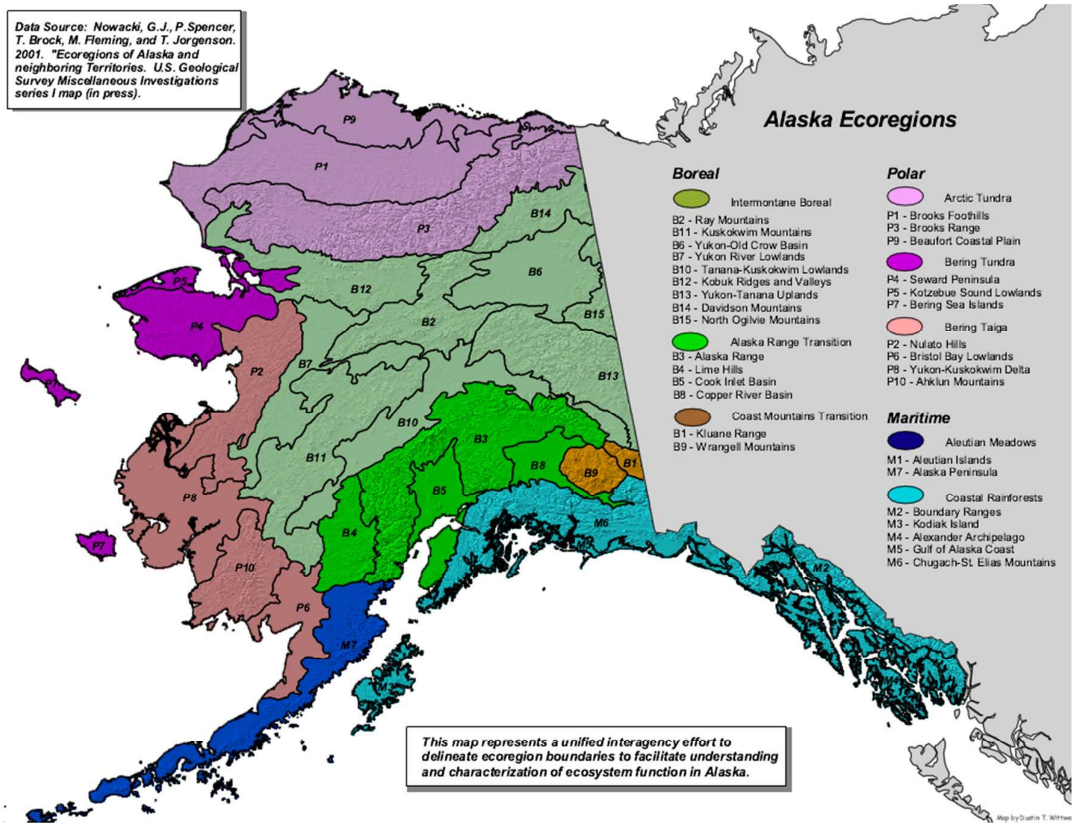

Figure II: Ecoregions of Alaska. In the final Model Ecoregions 2 were included, here shown by different colours

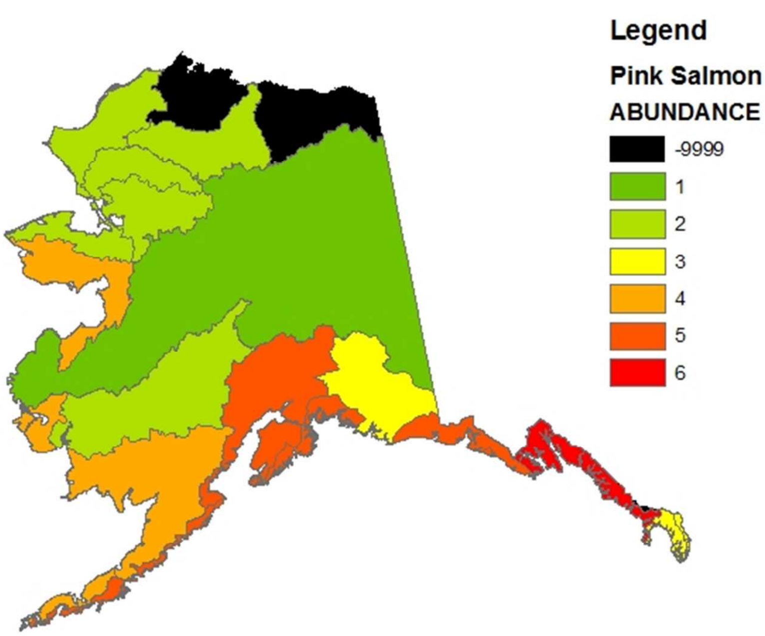

Figure III: Example for an abundance map of salmon in Alaska (here pink salmon). The missing data is marked with "-9999".

Appendix 4: Brief Metadata of the used GIS- layers

Table VI: GIS Layers and their sources

Input Variable	Source
Elevation	ArcView Image File (USGS 2009 http://agdcftp1.wr.usgs.gov/pub/projects/dem/300m/akdem300m.tar.gz
Aspect	ArcView Image File (USGS 2009) http://agdcftp1.wr.usgs.gov/pub/projects/dem/300m/akdem300m.tar.gz
Slope	ArcView Image File (USGS 2009 http://agdcftp1.wr.usgs.gov/pub/projects/dem/300m/akdem300m.tar.gz)
Ecoregions 1 and 2	Shapefile http://agdc.usgs.gov/data/usgs/erosafo/ecoreg/index.html)
Mean NDVI from 2000	Shapefile D. C. Douglas US GS Alaska Science Center, Biology & Geography Sciences, Juneau Office download at: (http://glcf.umiacs.umd.edu/data/)
Vegetation classes	Shapefile http://agdc.usgs.gov/data/projects/fhm/index.html#G
Temperature in June in December	ASCII (SNAP 2009) http://www.snap.uaf.edu/
Precipitation in June in December	ASCII (SNAP 2009) http://www.snap.uaf.edu/
Distance to coast	Shapefile: http://dnr.alaska.gov/SpatialUtility/SUC?cmd=vmd&layerid=56
Distance to lakes	Shapefile, Alaska Geobotany Centre http://data.arcticatlas.org/geodata/ak/
Distance to rivers	Shapefile http://gcmd.nasa.gov/records/GCMD_Alaska_Rivers_GIS.html
Fires 1950-1959 Fires 1960-1969 Fires 1970-1979 Fires 1980-1989 Fires 1990-1999	Bureau of Land Management http://agdc.usgs.gov/data/blm/fire/index.html
Distrubution salmon Coho Chinook Pink Steelhead Sockeye Chum	Shapefile http://www.stateofthesalmon.org/
Abundance salmon Coho Chinook	Shapefile http://www.stateofthesalmon.org/

Pink Steelhead Sockeye	
Human Footprint	Shapefile (CIESIN 2009) http://sedac.ciesin.columbia.edu/wildareas/
Human Influence Index	Shapefile (CIESIN 2009) http://sedac.ciesin.columbia.edu/wildareas/
Distance to roads	Shapefile http://dnr.alaska.gov/SpatialUtility http://www.mapcruzin.com/free-united-states-shapefiles/free-alaska-arcgis-maps-shapefiles.htm
Distance to towns	Tom Paragi, AK Fish & Game Dept Shapefile: http://dnr.alaska.gov/SpatialUtility
Distance to railways	http://dnr.alaska.gov/SpatialUtility
Distance to airways	Alaska Department of Natural Resources, Land Records Information Section. 1995. Airways Alaska. http://dnr.alaska.gov/Landrecords/

Appendix 5: Ground truthing

Table VII: Sample plots

no	north	west	elevation(m)	sample plot findings
0	64.47150000000	-141.20138000000	273	0
1	64.78283000000	-141.18208000000	268	0
2	64.91096000000	-141.18283000000	264	0
3	65.06440000000	-141.34310000000	253	0
4	65.09938000000	-141.42176000000	249	0
5	65.20341000000	-141.77488000000	241	0
6	65.23617000000	-141.91044000000	243	0
7	65.30177000000	-142.09286000000	247	0
8	65.33644000000	-142.41762000000	228	0
9	65.32145000000	-142.76871000000	220	0
10	65.32016000000	-142.86056000000	217	0
11	65.33639000000	-142.90748000000	218	0
12	65.35377000000	-143.32673000000	210	1
13	65.42670000000	-143.55746000000	203	1
14	65.82595000000	-144.06409000000	183	0

Figure IV: Sample plot 13